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Guidance on the Development of REGIONAL CLIMATE SCENARIOS for Vulnerability and Adaptation Assessments

UNDP UNEP GEF

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GUIDANCE DOCUMENT

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Guidance on the Development of Regional Climate Scenarios for Application in Climate Change Vulnerability and Adaptation Assessments

within the framework of National Communications from Parties not included in Annex I to the United Nations Framework Convention on Climate Change

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FOREWORD

There has been compelling scientific evidence that climate is changing. The effects of climate change have been widely felt and, no matter how successful we are in mitigation, we have committed a significant level of climate change through historical emissions of greenhouse gases into the atmosphere. Therefore, our natural environment and human society will have to adapt. To aid the decision-making for adapting to future climate, all non-Annex I Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are now planning for and/or implementing comprehensive national vulnerability and adaptation (V&A) assessments. Characterisation of future climate conditions (scenarios) constitutes a major component of the V&A studies and is a key input for most adaptation policy-oriented V&A assessments. However due to constraints in technical capacity, data and information availability and financing, non-Annex I countries were confronted with formidable difficulties in developing climate scenarios of satisfactory quality to support policy-relevant V&A assessments during Initial National Communications. Under Second National Communications (SNCs), non-Annex I countries have identified the refinement and improvement of climate scenarios as one priority for V&A work. This response reflects the increasing significance that non-Annex I countries are attaching to the national communication process as a strategic tool for, among others, developing national/sectoral adaptation strategies, policies and measures.

Within this context, I am delighted to launch this guidance document on the development and application of regional climate scenarios. This document builds on existing material and focuses on providing practical guidance on the key technical issues in relation to climate scenarios within the context of preparing SNCs. The document underlines the vital importance of a planning/scoping exercise to define clearly the needs for climate scenario information; describes a three-stage approach for climate scenario development; highlights documentation as an integral part of scenario development and provides a list of freely accessible sources of models, tools, data and guidance materials. This document uses extensive examples, primarily drawn from non-Annex I countries, to elaborate on methodological issues and to offer sources of information and data. I hope non-Annex I teams will find the document helpful in facilitating their efforts to improve climate scenarios under the SNCs.

As always, the National Communications Support Programme looks forward to receiving any queries and requests for further technical assistance on climate scenario development. In the meantime, any updates to the document will be made available to all non-Annex I SNC teams through the NCSP V&A Knowledge Network (*http://ncsp.va-network.org*).

Happy reading and good luck!

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1. INTRODUCTION

All Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are obliged to periodically report on the steps they are taking, or envisage undertaking, to implement the Convention [Articles 4.1 and 12 of the Convention, (United Nations, 1992)]. These reports are referred to as National Communications. National Communications constitute an essential information source for the Conference of the Parties (COP) to the UNFCCC to assess Parties' implementation of the Convention.

A set of revised guidelines for the preparation of national communications from non-Annex I (NAI) Parties was adopted at COP 8. These guidelines indicate that NAI countries shall provide information on their vulnerability to the adverse effects of climate change and on adaptation measures being taken to meet their specific needs and concerns arising from these adverse impacts. Specifically, NAI Parties are encouraged to include a description of methodologies, tools and data used, including scenarios for the assessment of impacts of, and vulnerability and adaptation to, climate change, as well as any uncertainties associated with these methodologies (UNFCCC, 2002). Therefore, the development, documentation and application of climate scenarios make up one important aspect of the preparation of national communications, mainly as part of the vulnerability and adaptation (V&A) assessment exercise.

However, V&A assessments in NAI countries have been hindered by a severe lack of quality data, capacity and resources to apply appropriate methods and tools. In relation to climate scenarios, NAI countries have reported limitations in using Global Climate Model (GCM) data for developing regional climate scenarios (UNFCCC, 2005). The need for assistance in constructing regional climate change scenarios that can support more policy-relevant V&A assessments has also been highlighted (Government of India, 2004). As various adaptation funds have now been created to support adaptation measures in NAI countries[1], demand has grown even higher for the national communication process to generate meaningful knowledge and information to inform adaptation decision-making. Indeed, many bilateral and multilateral donors use national reports such as National Adaptation Programmes of Action (NAPAs) and national communications to identify country priorities for adaptation. This has resulted in an increasing demand for better-quality climate scenarios to meet the information requirement of such V&A assessments.

Recognising the significance of wide implications of the selection of scenario methods and tools for the outcomes of the assessment, the Intergovernmental Panel on Climate Change (IPCC) Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA)[2] developed a series of guidance documents on the development and application of scenarios for climate impact assessments (IPCC-TGCIA, 1999; Mearns *et al.*, 2003; Wilby *et al.*, 2004). These materials were developed to serve the general climate change impact assessment community. Hence, they do not address specific issues (e.g., time and resource constraints, policy relevance at national and sub-national level, etc.) associated with national communication preparation in NAI countries, nor are they specifically intended to guide scenario development for supporting adaptation decisions.

More recently, the Consultative Group of Experts on National Communications from NAI Parties to the UNFCCC (CGE) developed a training package on climate change V&A assessments (http://unfccc.int/resource/cd_roms/na1/v_and_a/index.htm), of which climate scenario development is one part. This set of training materials, however, does not provide enough detailed guidance and information sources for constructing climate scenarios.

Further, the United Nations Institute for Training and Research (UNITAR) and the UNFCCC Secretariat jointly developed a computer-based training package, "VANDACLIM", under the CC:Train programme (Kenny *et al.,* 1997). VANDACLIM was designed for enhancing NAI country technical capacity for climate change impact and adaptation assessments. Climate and sea level rise scenarios can be created for a selected area/location on the imaginary island country, VANDA. As the first computer-based package, VANDACLIM was helpful in illustrating, among others, the key steps of undertaking a climate change impact assessments by linking primary data resources and sectoral impact models. However, the underlying data sets for creating climate scenarios within VANDACLIM are "hard-wired" for the fictitious island country and are out of date.

[1] There are currently four different funds for supporting adaptation measures in NAI countries: the **Special Climate Change Fund** (SCCF) (http://unfccc.int/cooperation_and_support/financial_mechanism/items/3657.php) and **Least Developed Countries Fund** (LDCF) (http://unfccc.int/cooperation_and_support/financial_mechanism/items/3660.php) under the UNFCCC, the **Adaptation Fund** (http://unfccc.int/cooperation_and_support/financial_mechanism/items/3659.php) under the Kyoto Protocol and the **Strategic Priority on Adaptation** (SPA) (http://thegef.org/Documents/Council_Documents/GEF_C27/documents/C.27.Inf.10OperationalGuidelinesforStrategicPriority.pdf) under the Global Environment Facility. See also http://www.undp.org/gef/adaptation for details on these different funds.

[2] Formerly the Task Group on Scenarios for Climate Impact Assessment (TGCIA)

This guidance document is intended to provide step-by-step guidance for developing climate scenarios within the framework of Second National Communications (SNCs)[3] from NAI Parties, taking into account data and technical constraints commonly encountered by these countries. The document is developed primarily for NAI country experts involved in preparing national communications. The document builds on existing guidance materials developed by the IPCC and CGE, but supplements them with more references to practical applications, examples and sources of data. A set of critical questions has been developed to guide the development of the scenario strategy within the V&A component of the national communication. Whenever possible, examples are given to help illustrate the various methods, which tend to be insufficient in existing guidance documents.

Key questions to guide the identification of needs for scenario information are highlighted in **Section 2**. General steps to develop climate scenarios and associated methods/tools for each of the steps are discussed in **Section 3**. **Section 4** provides a list of commonly used and publicly available models, tools, data sources and guidance documents for developing climate scenarios. Finally, **Section 5** summarises key messages in relation to the development and application of climate scenarios within the framework of national communications from NAI Parties to the UNFCCC.

[3] Hereafter, national communications refers to the Second National Communications unless otherwise stated.

2. IDENTIFYING NEEDS AND SELECTING SCENARIO APPROACHES

As climate scenario development can be rather resource intensive and time consuming, it is important to undertake an adequate scoping exercise to define clearly the needs for climate scenarios within the framework of the national communication. Figure 1 presents the key questions to consider while developing the climate scenario strategy. To begin, one needs to consider what kind of information about future climate is required in order to achieve the goals of a particular V&A assessment. Within the framework of NAI national communications, information on future climatic conditions is required to serve two general purposes: i) to communicate with policy-makers and the general public on climate change, for policy dialogues and awareness raising respectively; and ii) to provide inputs for climate change impact, adapation and vulnerability assessments.

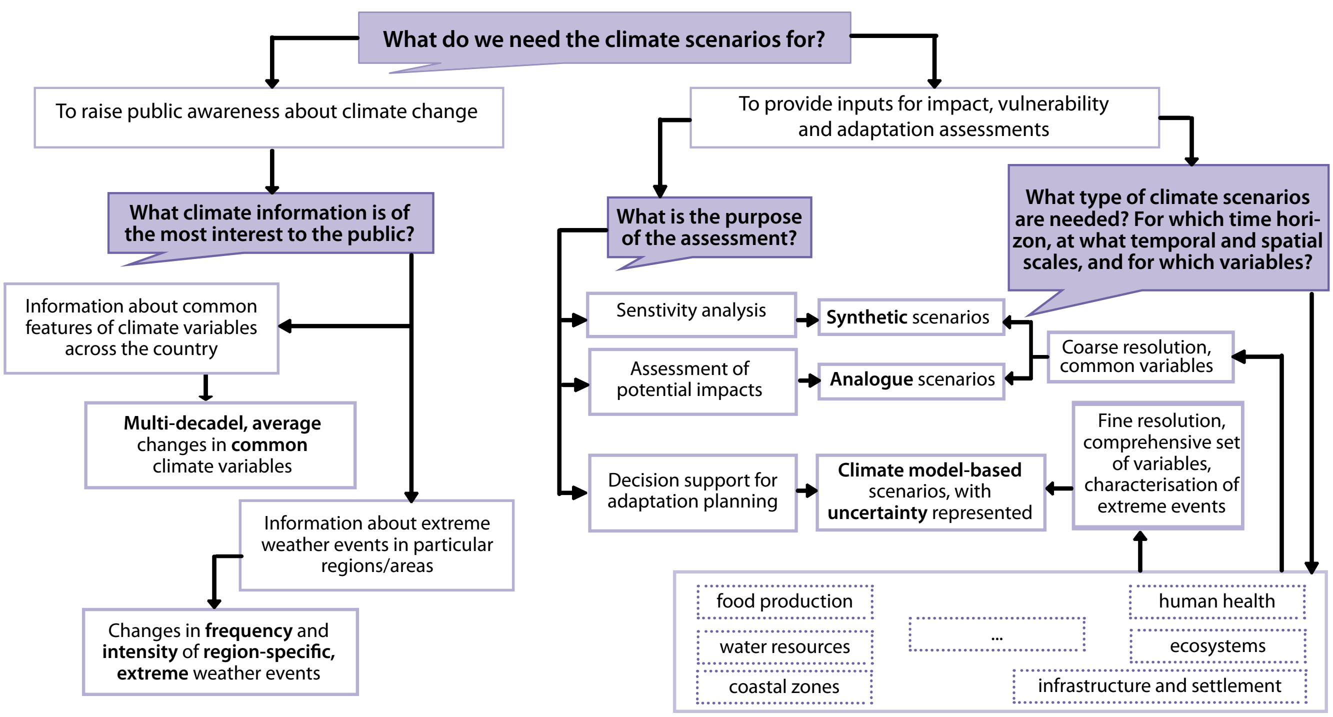


Figure 1: Questions to consider for identifying the needs for climate scenario information within the framework of national communications[4]

[4] The linkage between types of climate scenarios and purposes of V&A assessments is simply indicative and it is not meant to be definitive. In many cases, one may need to use a combination of different scenario types in order to carry out one type of assessment.

Despite growing awareness of climate-related risks as a result of recent extreme weather events, there is still a need to engage policy-makers and the general public in managing climate risks through dialogues and awareness raising. Presented appropriately, climate scenarios under future conditions can be an effective tool to communicate climate change with the public. Long-term historic data, where available, also helps to place climate change projections in context. Depending on the particular interest of the audience, and subject to availability of data and technical capacity, the details and format for presenting climate scenarios for public awareness raising can vary considerably. Scenarios can be simple diagrams – for example, presenting the projected trends in key climate variables, such as annual temperature and precipitation (Figure 2). Such (simple) information can convey a clear message to a general audience that has limited knowledge on the science of climate change. Procedures for extracting such scenario information are described in the subsequent sections in this document.

In contrast, where data availability and technical capacity permit, information on likely changes in the frequency and/or intensity of region-specific extreme weather conditions can also be of great interest to a wide range of potential users. Figure 3 presents an example of return periods of future extreme rainfall intensity with relation to the present-day, 20-year return period rainfall events in Southern Africa. Such information is particularly helpful for adaptation decision-making (e.g., flood-risk management). A further benefit of such detailed information is the production of maps that are visually appealing to the public and decision-makers alike. While demand for producing such technical information is high, specific knowledge is required to interpret and apply these data in practical situations. This expertise has been lacking in some NAI regions, but in recent years technical capacity has steadily improved and new scenario information generated from complex climate model simulations is becoming increasingly available. Hence, there is cause for optimism that

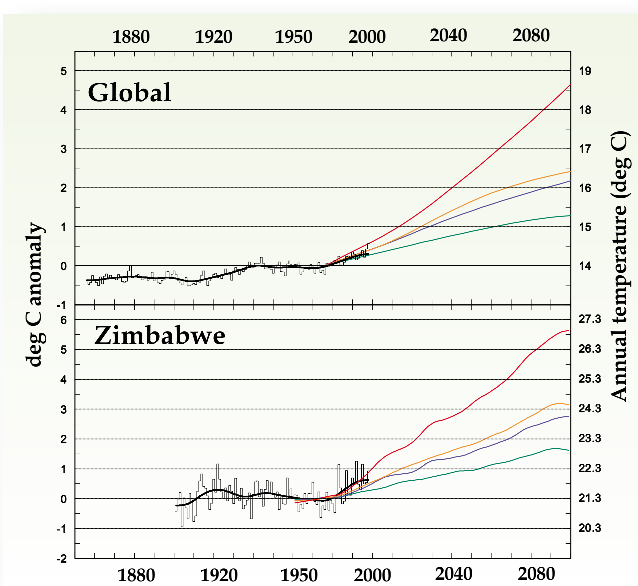


Figure 2: An example of a "simple" climate scenario for communicating to a general audience with limited knowledge of climate change. Shown in this diagram are the observed and model-simulated annual temperature changes to 2100 under four emissions scenarios (represented by the coloured solid lines) globally and for Zimbabwe. The change was simulated by a simple climate model with a medium climate sensitivity (2.5^0 C) and calculated in relation to the 1961-1990 average. Such scenario information is of particular interest to farmers and nature conservation practitioners alike (adapted from Hulme and Sheard, 1999).

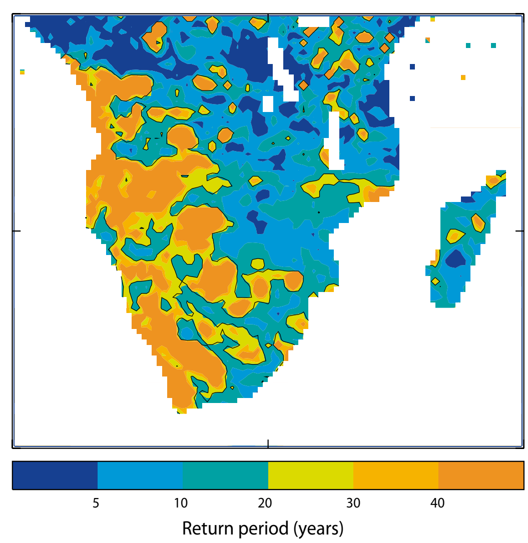


Figure 3: An example of "sophisticated" climate scenarios. Shown here are the summer rainfall return periods for the 2080s with relation to present-day, one-in-20-year events over Southern Africa, under the IPCC SRES A2 emissions scenario, as simulated by the UK Hadley Centre regional climate model, PRECIS. Values under 20 imply the present-day extreme precipitation event will be more frequent in the future, and vice versa (adapted from Jones *et al.*, 2004).

capacity to develop more sophisticated climate scenarios will be available in most NAI countries during the lifetime of the SNCs.

More commonly, climate scenarios are applied as inputs for assessing both the biophysical and socio-economic impacts of climate change, and the vulnerability and options for adapting to such impacts. The characteristics of climate change impact, adaptation and vulnerability (CCIAV) assessments are a fundamental determinant of which climate scenarios are needed. As illustrated earlier in Figure 1, the purpose, scope, spatial and temporal scales and time-frame of the assessment ultimately dictate the types, data sources and spatial and temporal resolutions of the scenario data required. Although there is no strictly defined, one-to-one correspondence between the type of assessment and the characteristics of climate scenarios, some common linkages can be made.

Generally, the more policy-oriented the assessment, the more demanding the scenario construction exercise becomes. As illustrated in Figure 1, assessments aimed at testing sector/system sensitivity to changes in key climate variables tend to use coarse-resolution and synthetic climate scenarios. To explore the potential impacts of future climate changes on specific sectors/systems, physically consistent climate scenarios are required. Depending on the sectors/systems of interest, these scenarios can have varying scales, both in time and space. If the assessment is aimed at informing the design of adaptation projects (e.g., building a reservoir to secure water supplies under a changing climate), then model-based climate projections with uncertainty represented (e.g., through conditional probabilities) are required to undertake risk assessments.

Since the 1980s, CCIAV assessments have progressively shifted from being applications of scientific curiosity to a policy-relevant orientation. The methodological frameworks applied to conduct the assessments have also become more sophisticated and multidisciplinary, along with the increasing needs for climate scenarios (Figure 4).

From the mid-1980s, numerous assessments have been carried out in NAI countries through a variety of international projects and national initiatives. Examples of international projects include the International Institute for Applied Systems Analysis/United Nations Environment Programme (IIASA/UNEP) study on climate change and agriculture (Parry *et al.,* 1988a, 1988b), the US Country Study Program (http://www.gcrio.org/CSP/uscsp.html) and the Assessments of Impacts and Adaptation to Climate Change in Multiple Regions and Sectors (AIACC) project (http://www.aiaccproject.org), while national projects include the Global Environment Facility (GEF)-funded enabling activities for the preparation of Initial National Communications (INCs). As illustrated in Figure 4, a vast majority, if not all, of these assessments either explored the sensitivity of a specific sector/system to common climatic variables – such as temperature and precipitation – or examined

- **UNFCCC** coming into force
- IPCC **1st** and **2nd** Assessment Reports

CCIAV assessments	Questions of investigation	Assessment frameworks	Climate scenario needs
First generation	Does climate change matter?	Sensitivity analysis	Synthetic scenarios
Second generation	What are the likely impacts of climate change?	Impact assessment	Analogue or climate model-based scenarios
Third generation	How to manage climate change-induced risk?	Risk management framework	Model-based projections with uncertainties quantified

- **Second** National Communications from NAI Parties
- IPCC **4th** Assessment Report

- **Initial** National Communications from NAI Parties
- IPCC **2nd** and **3rd** Assessment Reports

Figure 4: Summary of Climate Change Impact, Adaptation and Vulnerability (CCIAV) assessments and their requirements for climate scenario data.

the potential (largely biophysical) impacts on key sectors/systems. With increasing significance on international and national agendas attached to adaptation to climate change impacts, it is expected that the next generation of assessments (including those to be undertaken within the framework of SNCs) will need to address information needs for adaptation planning. Indeed, the national communication process presents a unique opportunity to generate policy-relevant knowledge and information for adaptation planning in general, and to lay the ground work for accessing the various adaptation funds. Hence, whenever technical capacity and data permit, efforts should be made to derive climate scenarios that are internally consistent (e.g., those from climate model simulations), with uncertainties explicitly quantified (e.g., through the use of a wide range of scenarios).

It is now technically more feasible to develop climate scenarios to support risk assessment than it was during the timeframe of INCs, because the results of model experiments are more readily available and more technical tools and methods have been developed (see Sections 3 and 4). But to ensure the policy relevance of the V&A assessments using these climate scenarios, SNC teams are strongly advised to engage stakeholders in scoping the assessment and identifying needs for scenario information. Figure 5 summarises the set of key questions to be considered when scoping the work on climate scenario development within the framework of national communications.

Using climate scenarios as a communication tool requires a greater attention to presentation aspects, but the scenarios must still have underlying scientific rigour and credibility. That is, the development of climate scenarios used in presenting results should not be different from, or less scientific than, scenarios developed for V&A assessments. For this reason, the remainder of this guidance document will focus on the development and application of climate scenarios for V&A assessments, as well as related methods, tools and data sources.

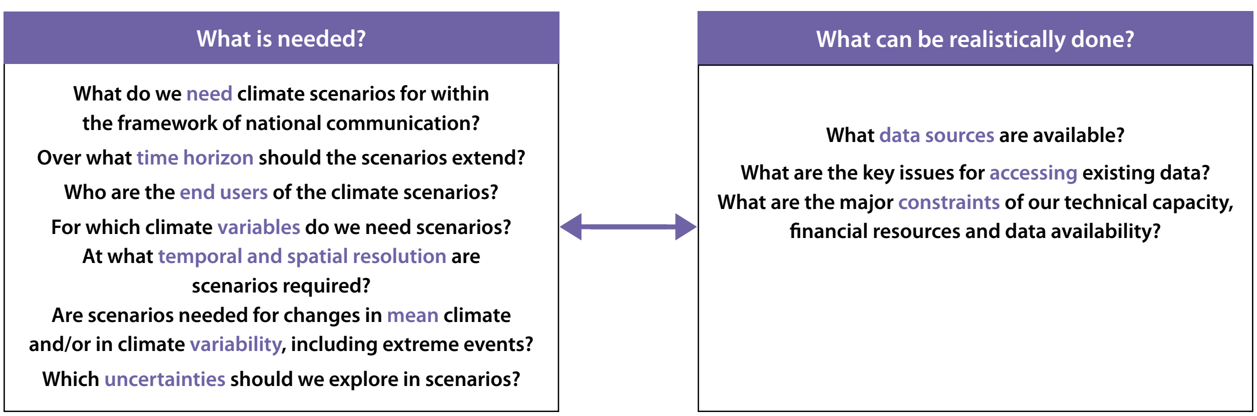


Figure 5: Key questions to consider when scoping the work on climate scenarios within the framework of national communications.

3 GENERAL STEPS FOR DEVELOPING CLIMATE SCENARIOS

Once the needs for climate scenario information are defined, a general procedure involving four steps can be followed for scenario development.

First, one needs to specify a baseline climate against which future changes in climatic variables can be measured and impacts assessed. Baseline climate data also help set the context for projections and characterise key features of the present climate regime (such as seasonality, extreme events and local weather phenomena). Depending on the purpose of the climate scenarios, the data sources and techniques required to define the baseline can vary widely. Section 3.1 discusses these in detail.

Second, changes in mean climate conditions and climate variability under enhanced greenhouse gas effects can be derived from a variety of data sources using different methods. A range of methods, tools and data sources for obtaining climate change information are discussed in Section 3.2.

Third, climate scenarios are constructed – in most cases, by combining model-based *changes* in climate with a *baseline* climate using observations. Section 3.3 provides guidance on procedures for obtaining climate scenarios using these sources of information.

As discussed in Section 3.2 below, climate model outputs have been the most common source for climate scenario development. However, climate models are not yet skillful in representing some of the complex physical processes within the climate system, particularly those at the regional scale. There is often bias in model simulations towards the absolute state of the climate system. But climate model outputs can be used to derive important information about the changes in climate variables under enhanced radiative forcing due to increased atmospheric greenhouse gas concentrations. Therefore, to characterise the absolute state of future climate, *climate change scenarios*, derived primarily from climate model simulations are combined with (observed) climate baselines (e.g., Carter *et al.*, 2001).

Definitions of baseline climate, climate change scenarios and climate scenarios are given in Box 1.

Fourth, detailed documentation should be prepared to describe the methods, tools and data sources used to develop climate scenarios, as well as the caveats and limitations and to provide guidance on scenario interpretation and its intended uses.

Box 1: Baseline climate, climate change scenarios and climate scenarios

A **baseline climate** is the climatic conditions that are representative of present day or recent prevailing climatic trends for a given period of time in a specific geographic area. A baseline climate describes average conditions, spatial and temporal variability and anomalous events over the baseline period. It also provides a benchmark against which to measure future changes in climatic variables and to assess the impacts of future changes. In addition, impact assessors might use baseline climate data to calibrate and test impact models. Good-quality observed climatological data are often required to define a baseline climate.

Climate change scenarios describe plausible future changes in climate variables and are usually measured with respect to baseline climate conditions[5].

Climate scenarios describe possible future climates. Although climate change scenarios can be applied directly to support risk analysis, most (biophysical) impact assessments require inputs of future climate *states*, rather than *changes*, with relation to the baseline reference period, in order to assess potential impacts of projected changes in climate. As discussed below, climate scenarios usually (although not always) combine observed baseline climate with estimates of future climate changes. These possible changes are often (although not always) derived from climate model outputs.

Figure 6 illustrates these general steps for developing climate scenarios within the framework of preparing SNCs.

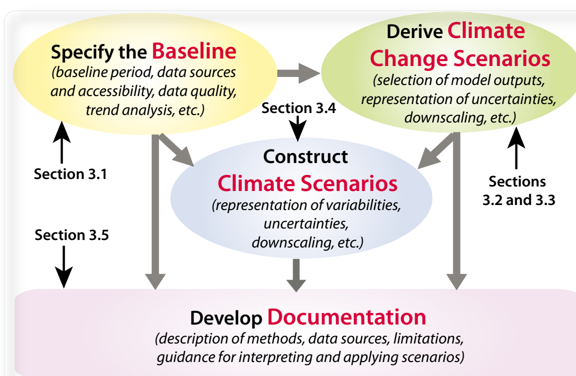


Figure 6: General steps for developing climate scenarios, with references to the sub-sections where they are discussed.

[5] The baseline climate here is usually a modelled one.

3.1 Specify the baseline climate

In order to characterise present-day climate conditions in a given geographic area, good-quality observed climate data are required for a given baseline period. The following questions need to be considered when defining the baseline climate.

3.1.1 What climate scenario data are needed?

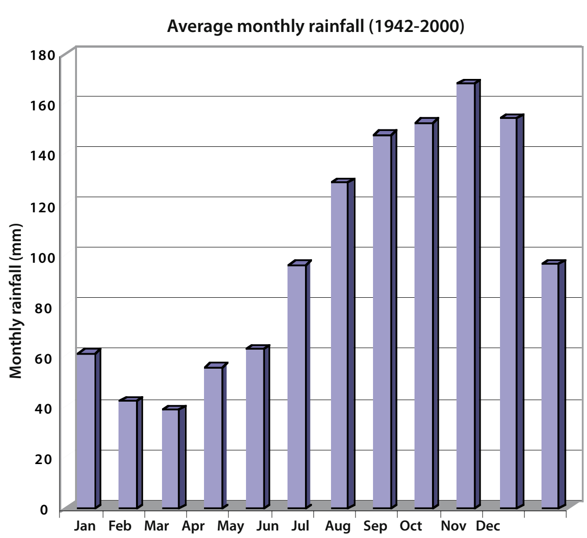
As discussed in Section 2, climate scenario data requirements can vary widely – from a single variable to a comprehensive suite of variables, from local to extensive spatial scales, and from sub-daily to multi-decadal or even century time scales. Surface air temperature and precipitation are the most commonly required variables. However, other surface variables such as evaporation rate, solar radiation, humidity, wind speed and snow cover may be required for some assessments.

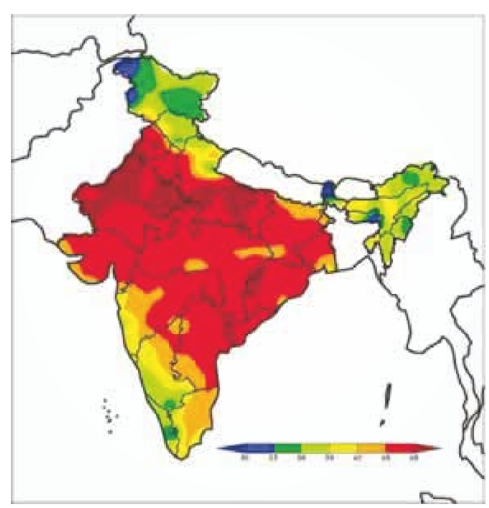
The baseline climate should provide sufficient information on those present-day conditions that will be characterised in the scenarios under a changing climate at the appropriate temporal and spatial scales. For example, if the concern of a country is the multi-decadal temperature and precipitation patterns as they are associated with the popularity of the country as a tourist destination, the baseline climate will need to provide background multi-decadal information for these two variables. Or, if future trends in extreme rainfall events are of concern, then observed daily or sub-daily rainfall data for the baseline period will be required to analyse the characteristics of the extreme rainfall events under present-day conditions. Different assessments also place different requirements on the spatial scale of climate scenarios. For example, if the assessment is concerned with a large river catchment, the baseline climate will need to provide regional patterns of rain depth and evaporation rate. This often requires the use of interpolated data over a grid using specific tools (e.g., krieging methods, Geographic Information Systems, etc.). If the focus is a small urban area, then a single-site, chronological series of data (e.g., from the nearest meteorological station) will be required. Figure 7 provides two examples of baseline climatologies.

3.1.2 Which baseline period should be selected?

Although the selection of baseline period is dictated by the availability of good-quality observed data, the duration of the baseline climate also needs to be (IPCC-TGCIA, 1999):

(1) Representative of the present-day or recent average climate in the region;
(2) Of a sufficient duration to encompass a range of climatic variations, including a number of significant weather





Spatial patterns of observed extreme daily maximum temperatures (°C) over India.

Figure 7: Two examples of climate baselines. *Above left:* Observed long-term average monthly rainfall in Barbados (adapted from the Government of Barbados, 2001). *Above right*: Spatial patterns of observed extreme daily maximum temperature for 1961-1990 over India (adapted from the Government of India, 2004).

anomalies (e.g., severe droughts or extremely hot summers), and sufficiently short to exclude climate trends;

(3) Covering a period for which data on all major climatological variables are abundant, adequately distributed over space and readily available; and

(4) Consistent or readily comparable with baseline climatologies used in other assessments for the region.

A popular climatological baseline period is a non-overlapping, official, 30-year, "normal" period (e.g., 1900-1930, 1931-1960, 1961-1990) as defined by the World Meteorological Organization (WMO). The current WMO normal period is 1961-1990 (IPCC-TGCIA, 1999). To ensure comparability and consistency of assessment results, countries are encouraged to adopt this baseline period. But, if data availability so determines that an alternative period is adopted instead, the criteria listed above should be considered.

3.1.3 What data sources are available?

There is a range of data sources that can be used for defining baseline climatologies. These sources can be categorised as:

National meteorological agencies and archives

National meteorological agencies maintain the day-to-day operations of weather observations and publish weather statistics. Therefore, these agencies and their archives are often the primary sources of observed climate data, particularly at daily or sub-daily intervals. However, many NAI countries reported in their INCs that they had difficulty in accessing quality-controlled, observed weather data. Therefore, at the outset of the national communication project implementation, it is very important for the National Communication Steering Committee (or other institutions managing the national communication project) to ensure institutional arrangements are in place to grant free access to this observational climate data for the national communication team.

Supranational and global data sets

Observations from different countries have been combined into various supranational and global data sets, typically using funding from Annex I country governments and/or international organisations. These data sets often include mean values for surface variables for various periods, interpolated to a regular grid. But with improved processing and storage capacity, there are now also a number of historical data sets providing annual, monthly and even daily time series of gridded or site observations (see Section 4.2 for a list of supranational and global data sets).

Weather generators

Weather generators are statistical models that describe the properties of an observed climate variable in a region using few parameters. The ability to generate a climatological time series of unlimited length can be particularly helpful in regions with sparse observed data. In some cases, a weather series can be generated from statistical parameters obtained from observed data at a neighbouring site or at sites with sparse or broken records. An example of a widely used weather generator is LARS-WG (http://www.rothamsted.bbsrc.ac.uk/mas-models/larswg.php) (Semenov and Barrow, 1997).

Climate model outputs

Two types of data from GCM simulations can be used for specifying climate baselines: reanalysis data and outputs from GCM control simulations.

Reanalysis data

To overcome the problem of sparse and irregular meteorological observations often found in NAI countries, reanalysis data can be used for defining baseline climatologies. These are fine-resolution, gridded data which combine observations (usually sparse and irregular in distribution) with simulated data from climate models through a process called data assimilation. In addition to filling gaps in conventional observations of surface variables, the assimilation process can provide estimates of unobserved quantities such as vertical motion, radiative fluxes and precipitation. Therefore, reanalysis data have been very helpful for establishing statistical relationships between locally observed surface variables and large-scale, upper-air-circulation indices. Such relationships are needed to statistically downscale coarse-resolution GCM outputs to create local-scale climate scenarios. Section 3.2 has a more detailed discussion.

Outputs from GCM control simulations

GCM control simulations attempt to represent the dynamics of the global climate system unforced by anthropogenic changes in atmospheric composition. Most Atmosphere-Ocean GCMs (AOGCMs) control simulation runs over multiple centuries, and hence can provide data for analyses of natural variability of regional climate. Since actual observations barely extend beyond one century in duration, model control simulations offer an alternative source of data-enabling impact analysis for investigating the impact of multi-decadal variations in climate. Control simulation data from a range of AOGCMs are currently available from the IPCC Data Distribution Centre (DDC) (see Section 4.2 for more details on data sources).

3.1.4 How can climate baselines be applied for the V&A assessment?

The primary objective in applying baseline data in an impact assessment is to characterise the sensitivity of the exposure unit to present-day climate. Typically, this involves first using part of the data to calibrate and test the impact models and, second, running the models with input data from the entire baseline period to estimate reference impacts. In particular, baseline climate data can be used for analyses of extreme events as well as time series. IPCC-TGCIA (1999) discusses various alternatives for applying climate baselines for climate scenario development and impact assessments.

Within the context of SNCs, the selection of the climate baseline has implications for the relevance of V&A studies to adaptation project development. To be eligible for financing from GEF adaptation funds[6], proposals need to demonstrate that adverse impacts and vulnerability to be addressed by the project result from climate change, *not* from natural climate variability.

There are several possibilities for "verifying" risks resulting from anthropogenical climate change. One is to study long-term observational data, if they exist, and to calculate summary statistics. There may be trends in the data that make it difficult to determine whether the observations are exhibiting long-term natural variations or anthropogenically-induced trends. However, some information may be gleaned by comparing the observations with outputs from long-term, unforced climate model simulations.

The observed data also offer a test of the climate model's ability to represent observed multi-decadal variability. By definition, an unforced climate simulation should not exhibit long-term trends, although some models do experience "drift" (for a more detailed discussion, see McAvaney *et al.*, 2001). After scrutinising both observed and unforced climate model data, one could then estimate natural variability and further characterise long-term climate change using forced climate model outputs. Comparison between the impacts resulting from natural variability (from observations of the past) and those from long-term changes (from the climate model output) in the regional climate could then be used to illustrate the relative significance of projected future climate change.

[6] See http://www.undp.org/gef/adaptation/index.htm for details on the various GEF adaptation funds and funding eligibility criteria.

3.2 Develop climate change scenarios – general approaches

Once the baseline climate is established, there are several possible approaches that can be employed to develop scenarios of future climate changes:

3.2.1 Assume arbitrary changes in climate variables

Arbitrary adjustments of the baseline climate (commonly at regular intervals) can be used as an input to sectoral impact models. One possible output of such an exercise is the construction of a "response surface" – a diagram that shows how a given impact variable responds to different levels of climate change. For example, temperature increases of +1^{0}C, +1.5^{0}C, +2^{0}C, etc., could be applied to a crop model to test the sensitivity of crop growth to temperature change. Similarly, precipitation could be adjusted by ±5%, ±10%, ±15%, etc., to estimate the impacts of such changes on the same crop. Figure 8 provides an example of "arbitrary" temperature change scenarios used to analyse sensitivities of crop yields in northern India. From such sensitivity analyses, critical thresholds and non-linear responses of sectors/systems could be identified.

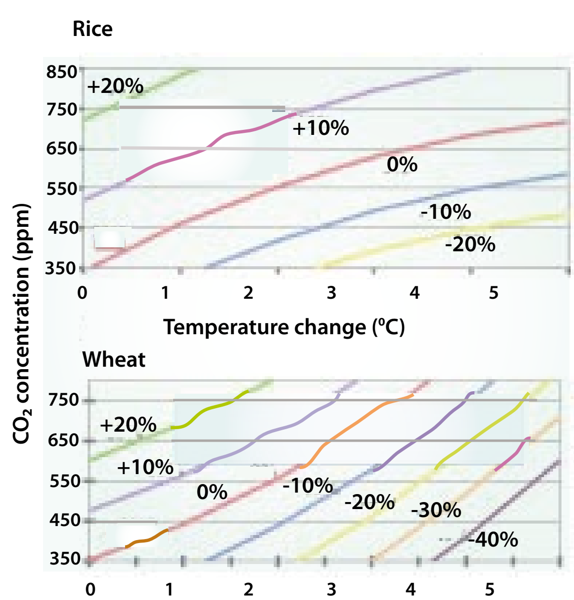


Figure 8: Incremental temperature change scenarios applied to simulate the response surface of irrigated rice and wheat yields in northern India. The contours represent the percentage changes in grain yields at different CO_2 concentrations and temperature rise levels (adapted from the Government of India, 2004).

Artificial scenarios that assume arbitrary changes in variables are easy and quick to construct, apply and interpret, and they are useful in testing the sensitivity of biophysical systems. However, some caution should be exercised as these arbitrary changes can be physically inconsistent – particularly when a combination of arbitrary changes for different variables is applied at the same time. For instance, precipitation decrease might be physically implausible with temperature rise for a given region. In addition, arbitrary adjustments are commonly applied for the whole year and assume that other characteristics of the baseline climate remain unchanged (e.g., inter-annual, daily and diurnal variability). Unless more sophisticated sensitivity studies are applied, this approach risks overlooking the potentially important effects of seasonality and variability change in future climates. This is why model projections can be helpful either in complementing arbitrary adjustments or as support in designing "guided sensitivity analysis". Finally, such artificially assumed changes may not be consistent with (more physically sound) model projections for the region being studied. Therefore, it is advisable to *use the model projections as a rough guide to develop arbitrary climate change scenarios*. If the results suggest further detailed impact analysis is warranted (i.e., the system under investigation is significantly sensitive to changes in key climate parameters), more physically-based scenarios, mostly from climate model outputs, should be developed to support more detailed assessment of climate change impacts.

3.2.2 Use temporal and spatial analogues

This approach involves identifying recorded climate regimes that may resemble the future climatic conditions for a given region. The recorded regime could be from the past (*temporal analogue*) or from a different region in the present (*spatial analogue*). For example, climate records from warm periods in the past could be used to analyse potential impacts under a warmer climate in the future. Similarly, the likely effects of a changing climate in a currently cooler region (e.g., countries in northern Europe) could be examined by using present-day climate observations from a warmer location (e.g., countries in south Asia).

Since analogues make use of observed climates, they are physically consistent. A further advantage of analogue scenarios is that they can provide detailed information on likely impacts, particularly those associated with extreme events (e.g., heat waves or extreme droughts) that require certain forms of adaptation measures. Examples of analogues judged likely or very likely by the end of this century include the European 2003 heatwave (Kjellström *et al.*, 2006) and flooding (due to more intense summer precipitation) in Bangladesh (Mirza, 2003).

However, it is not always easy or straightforward to identify analogues and there are several caveats one needs to be aware of when applying analogues for CCIAV assessments. First, analogues identified by using one climate variable (e.g., temperature) do not always contain consistent records for other variables (e.g., precipitation). Second, past periods of climate that may appear to resemble anthropogenically-induced future climate (e.g., they are warmer than present) may not be good analogues in other respects because the cause of the warming is different (i.e., forcing due to natural variations in earth orbital variations, ocean circulation changes, etc., is different to greenhouse gas-induced warming). Third, even if the climate offers a good spatial analogue, other important contributory factors to impacts (e.g., socio-economic conditions, soils, latitude/day length) may be quite different. Finally, some factors such as length of day or local climate forcing (e.g., due to lake or coastal influences) are not transferable between locations.

3.2.3 Develop scenarios from climate model outputs

The most common approach to deriving climate change scenarios is to make use of climate model outputs. Three types of climate models have been developed to provide projections of future climate changes, each with progressively higher resolution: simple climate models, GCMs and Regional Climate Models (RCMs).

Simple climate models

Simple climate models are one-dimensional, energy-balance models – that is, they do not include horizontal exchange of mass and energy. These models provide global projections of annual temperature change and sea level rise. Since simple climate models do not provide regional details of future climate change, their outputs are rarely applied to develop climate change scenarios with regional details, such as those developed within national communications. However, as it is easy to run many simulations within a short time and generate results rapidly, global projections from these models have been used in conjunction with GCM and RCM outputs to explore uncertainties associated with climate scenarios (see below).

The Model for the Assessment of Greenhouse gas Induced Climate Change (MAGICC) is one example of a simple climate model (Wigley and Raper, 1992). MAGICC can be used on its own but has also been designed to be used in conjunction with a global and regional SCENario GENerator (SCENGEN), which contains outputs from a set of GCM experiments and analytical modules. More details on MAGICC/SCENGEN are provided in Section 4.1.

General Circulation Models/Global Climate Models

GCMs are mathematical representations of physical processes in the atmosphere, ocean, cryosphere and land surface. GCMs depict the climate using a three-dimensional grid over the globe, typically with a horizontal resolution between 250-600 km, 10 to 20 vertical layers in the atmosphere and as many as 30 ocean layers (Figure 9). The GCM's resolution is thus rather coarse relative to the scale of exposure units in most impact assessments. Thus, downscaling or regionalisation techniques are required to "transfer" the coarse-resolution GCM outputs to the regional/local scales required for CCIAV assessments.

Nonetheless, with their physical consistency and satisfactory skill in representing observed climate and past climate changes, GCMs have proved to be important tools for simulating and understanding climate. However, they also exhibit weaknesses, such as an uncertain representation of clouds and a limited ability to reproduce El Niño-Southern Oscillation (ENSO) type phenomena, which reduces confidence in the magnitude and timing of projected climate changes, especially at regional scales. Nevertheless, over several decades of model development, GCMs have consistently provided a robust and unambiguous picture of climate warming in response to increasing greenhouse gases.

GCMs are the only tools currently available to simulate the response of a regional climate system to increasing greenhouse gas concentrations. Although simpler models such as MAGICC have also been used to provide large-scale (usually global) projections of climate change, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change that are required in CCIAV analysis (IPCC-TGCIA, 1999).

GCM outputs have been the most common approach to climate change scenario development. Section 3.3 discusses different methods for developing climate change scenarios from GCM outputs.

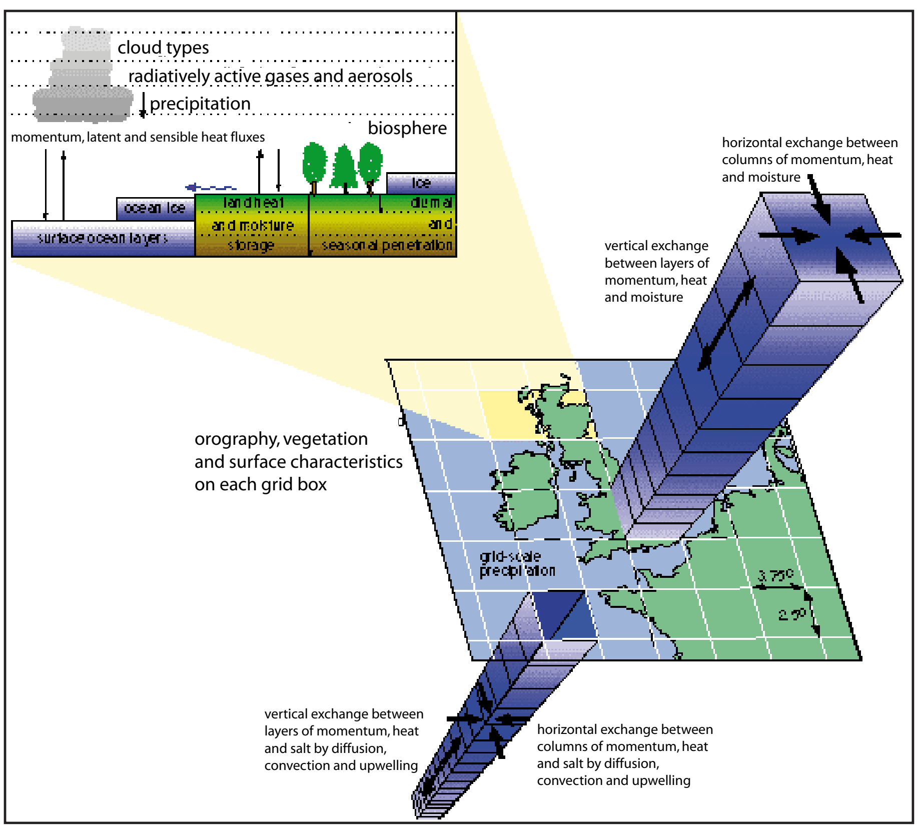


Figure 9: Schematic representation of a GCM (adapted from Viner and Hulme, 1994)

Regional Climate Models

For many applications, particularly those at sub-national or local scales, the regional climate change information provided by GCMs has proved insufficient (UNFCCC, 2005). Therefore, downscaling techniques are required to provide more regional information in climate change scenarios.

Regional climate modeling is one approach to improving the spatial resolution of GCM information. RCMs use outputs from GCM simulations as initial conditions and time-dependent, lateral, meteorological boundary conditions. As they cover a limited domain, the horizontal resolution of RCMs can be increased to 50km × 50km, or higher. As with GCMs, development of RCMs has largely been limited to a few, well-resourced modelling centres in developed countries. But with increasing investment in human capacity and computing infrastructure, regional climate modeling capacities are starting to emerge in NAI countries. For example, the Centro de Previsão de Tempo e Estudos Climáticos in Brazil has been developing an RCM and performing experiments with it for the South American region and, with assistance from the UK Hadley Centre, a number of NAI countries (China, Cuba, India, Jamaica, South Africa) have been running the Providing REgional Climates for Impact Studies (PRECIS) model[7] to generate regional climate change scenarios.

A detailed guidance document on how to use RCM outputs for constructing scenarios and their applications in impact assessments was developed by Mearns *et al.* (2003) under the TGICA. The document is available at http://ipcc-ddc.cru.uea.ac.uk/guidelines/dgm_no1_v1_10-2003.pdf.

Details on data sources from RCM experiments that could be used by NAI countries for climate change scenario development are provided in Section 4.2. It is worth noting that data of sufficient quality (for validating the skill of RCM experiments in representing regional climate regimes under current climate) is often a limiting factor for NAI countries to develop RCM-based climate scenarios. This is discussed in detail in Mearns *et al.* (2003).

3.3 Develop climate change scenarios – using outputs from GCM experiments

As noted above, most climate change scenario development uses GCM outputs. This section details this approach.

3.3.1 Selecting GCM outputs

Over the past two decades or so, numerous experiments have been carried out with a wide range of GCMs. Apart from differences in the representation of relevant physical processes by various GCMs, different greenhouse gas and aerosol emissions scenarios were used to force these experiments. Earlier equilibrium experiments were run to estimate the climate responses to a doubling of atmospheric concentration of greenhouse gases or its radiative equivalent. While outputs from these experiments are very helpful in model comparisons, the equilibrium GCM experiments are unrealistic as the atmospheric composition is not static. Hence, no provisions have been made to provide outputs from these experiments to general users. Advances in GCMs have made it possible to simulate the transient-response of climate to a time-dependent change in greenhouse gas concentrations. Thus, outputs of such transient experiments can provide useful information on the rate and magnitude of climate change. In addition, experiments were also carried out to account for the effects of sulphate aerosol loading (with cooling effects) in combination with greenhouse gas forcing.

Under a variety of international initiatives, the outputs of a large number of GCM experiments were made publicly available for non-profit application at no cost. Section 4.2 provides details on GCM experiments for which outputs are available.

While it is encouraging that increasing amounts of data are being made available, the resulting wide choice can sometimes lead to confusion and make the task of selecting the appropriate model outputs rather challenging. Although there are no clear-cut rules as to which outputs one should work with, the following are general criteria that could help in the selection of model experiments (IPCC-TGCIA, 1999):

Model vintage

To incorporate advances in science and reap the benefits of ever-growing computational power, modelling centres update their GCMs from time to time. Therefore, it is advisable to use data from experiments performed using the latest model version. For example, various experiments were carried out with the two versions of the Hadley Centre GCM (HadCM2 and HadCM3). So, all other features of the experiments being the same, one would opt for data from the later-generation HadCM3 experiments[8].

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[7] See http://www.precis.org.uk for details on PRECIS and its application in NAI regions.

[8] However, users may have to use experiments performed with older-model version if the impacts are to be assessed under a particular emission scenario for which data is only available from simulations performed with an older-model version.

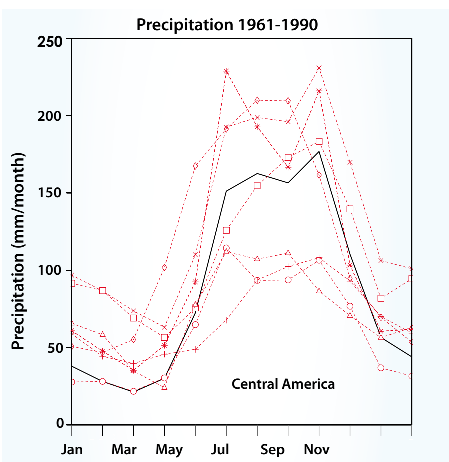
Model resolution

With model refinement and increased computing power, the spatial resolution of GCMs has improved over the past decade. If regional details (e.g., topographic features) will be important in the application of the climate scenarios (e.g., orographic rainfall), then outputs of experiments performed with GCMs of a higher resolution are usually preferred. However, it is important to note that higher spatial resolution does not necessarily mean more accurate performance of model experiments.

Validity of the outputs

Validity of the outputs is often a more persuasive criterion. One tends to be more comfortable working with models that can reproduce observed climate for a given region with greater accuracy. Therefore, before deciding upon which GCM outputs to use, one usually carries out "validation" analysis by comparing model-simulated current climate against climate observations. Comparisons could either be between the simulated and observed multi-decadal average quantities (Figure 10, top panel) or between a time series, to see whether the observed climate variability is adequately captured by model simulations (Figure 10, bottom panel). In addition, spatial comparison of modelled and observed climatology could be made (see Figure 11 for an example). One also needs to refer to published skill measures (such as pattern correlation, e.g., Giorgi and Mearns, 2002) or the findings of inter-comparison studies (e.g., Ruosteenoja *et al.*, 2003; Tebaldi *et al.*, 2006).

It should also be noted that a model experiment with a high level of accuracy for reproducing present-day climatic features does not guarantee the accuracy for modelling future climate conditions under enhanced radiative forcing. This is, in part, due to the fact that most model parameterisations use observations under present-day climate, but these may not be valid under a changing climate regime.



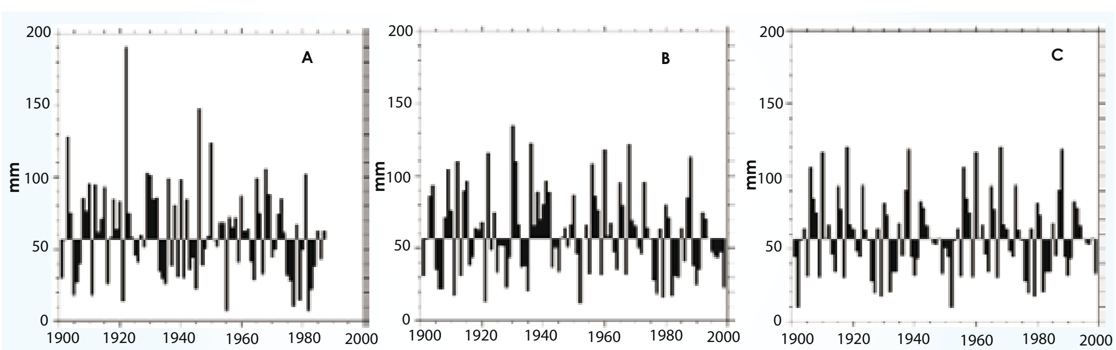
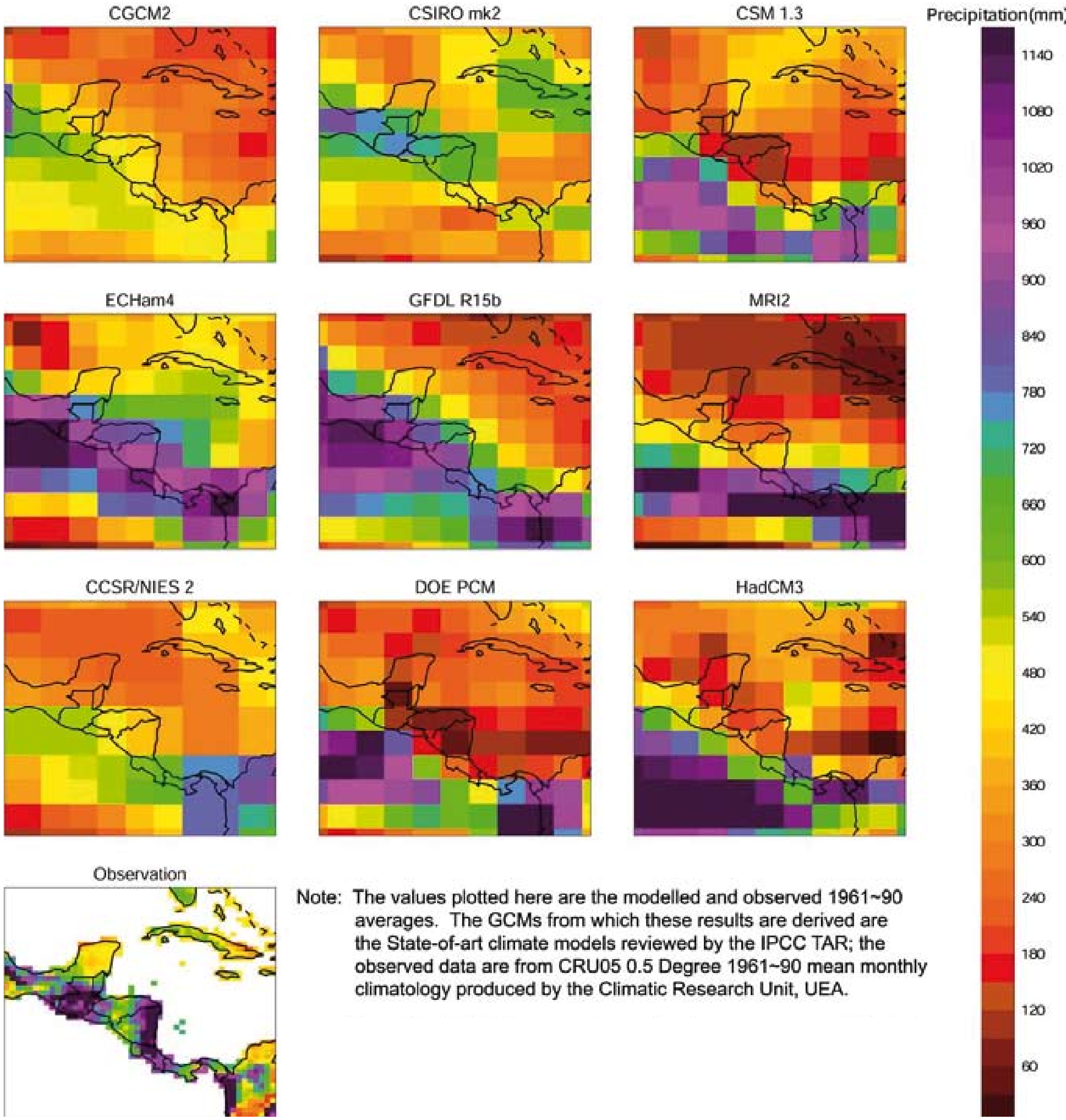


Figure 10: Evaluation of GCM validity through a temporal comparison between observed and simulated "present-day" climate. *Top panel:* Comparison between observed and GCM-simulated multi-decadal average monthly precipitation in Central America (Ruosteenoja *et al.*, 2003); *Bottom panel:* July precipitation from: observed single station record (A); observed average within grid box (B); and model (HadCM3) simulations (C) (adapted from Mitchell *et al.*, 2004).



Note: The values plotted here are the modelled and observed 1961~90 averages. The GCMs from which these results are derived are the State-of-art climate models reviewed by the IPCC TAR; the observed data are from CRU05 0.5 Degree 1961~90 mean monthly climatology produced by the Climatic Research Unit, UEA.

Figure 11: Evaluation of GCM validity through a spatial comparison between observed and simulated "present-day" climate. Shown here are modelled (as denoted by different GCMs) and observed 1961-1990 average June-July-August precipitation for Central America (*Source*: AIACC, http://www.aiaccproject.org/resources/resources.html).

Representativeness of results

Due to differences in the representation of relevant processes by GCMs and in the initial conditions of GCM experiments, projections of future climate change – even forced with identical emissions scenarios – can vary widely from model to model. Figure 12 illustrates different model projections for southern Africa forced by the SRES A2 and B2 emissions scenarios. As shown in the figure, most models project rainfall increases in most seasons. However, some models suggest decreases in rainfall – especially in June-July-August (JJA) where the HadCM3 model projects an 80 per cent decrease under the A2 emissions scenario. It is advisable to select model outputs that represent the full range of projections. For example, if one were to derive JJA rainfall climate change scenarios for the southern Africa region based on the GCM outputs shown in Figure 12, the simulations performed with HadCM3 (for its projections of large decrease in rainfall under both A2 and B2 scenarios), CSIRO mk2 (for its projection of a high increase in rainfall under the B2 scenario) and DOE PCM (for its small changes in rainfall under both emissions scenarios) would need to be selected in order to consider the full range of projected changes. Choosing a representative range of climate change scenarios is of particular importance if the scenarios are to support risk assessment, which in turn informs decisions on operational adaptation measures to manage and reduce climate risks (e.g., to inform the design of a reservoir for securing water supply under a changing climate).

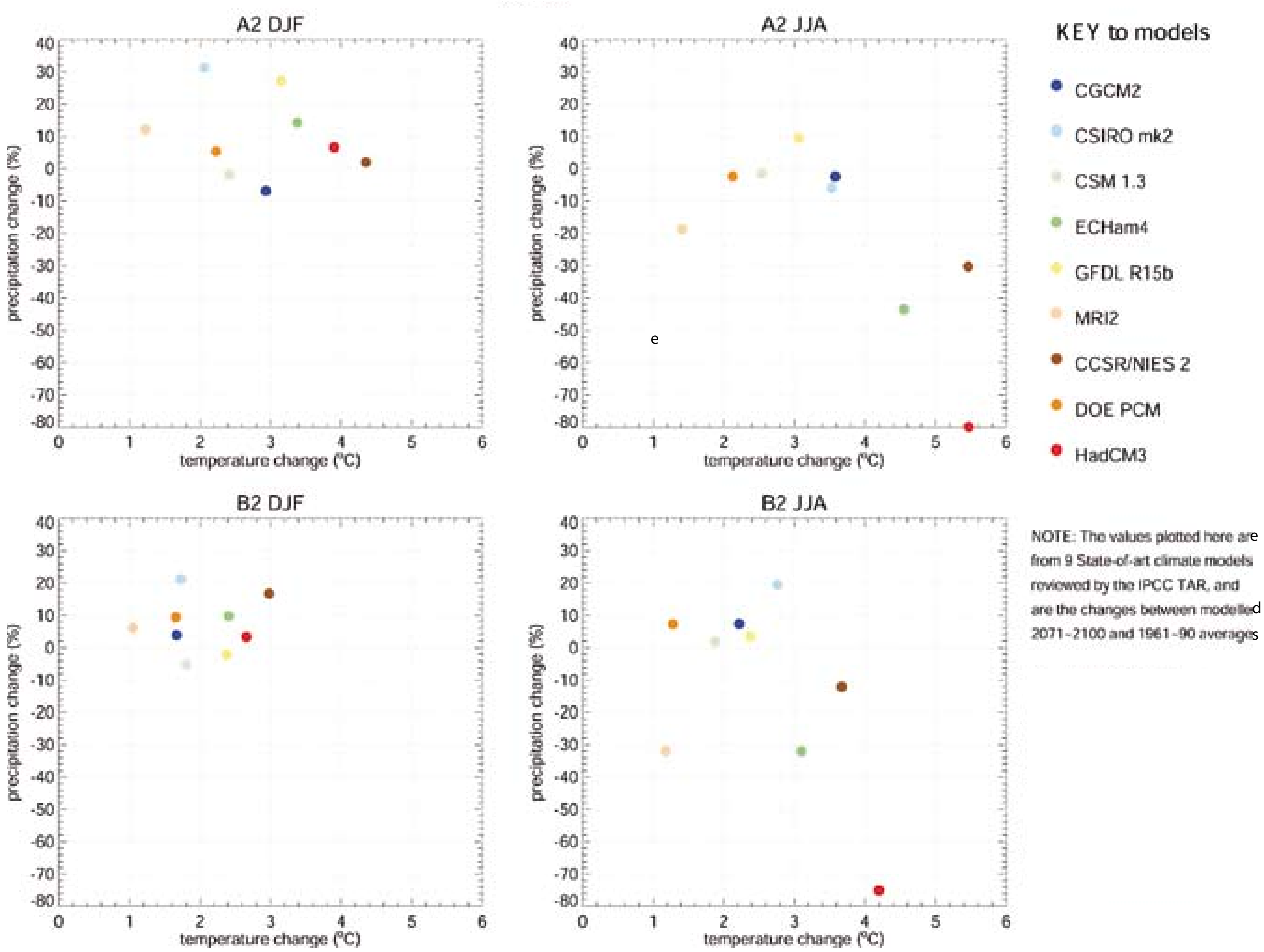


Figure 12: Seasonal temperature and precipitation changes over southern Africa for December-January-February (DJF) and June-July-August (JJA) as simulated by nine GCMs, forced by the SRES A2 and B2 emissions scenarios (*Source*: AIACC, http://www.aiaccproject.org/resources).

3.3.2 Deriving climate change scenarios directly from GCM outputs

To date, numerous experiments have been performed with a wide range of GCMs forced by a variety of greenhouse gas and aerosol emissions scenarios. Scenarios of monthly or seasonal changes for a set of surface variables can be derived from outputs of these experiments. Such changes can be either monthly time series (mostly between 2000-2100) or multi-decadal (e.g., 30 year) average values. With time-series scenarios, analyses can be carried out to examine the changes in inter-annual variability; this is not possible with multi-decadal average scenarios.

Figure 13 presents an example of JJA precipitation change scenarios directly derived from a set of nine GCM experiments forced by the SRES A2 emissions scenario for southeast Asia, at GCM native grids. Due to their coarse resolution – both in time (monthly time step) and space (several hundred kilometres) – scenarios directly derived from GCM outputs often fall short in providing regional detail and information on changes in short-term processes (e.g., extreme rainfall events at daily scale) for most applications, particularly those considered in national communications. Further analysis (i.e., downscaling) is often required to obtain more detailed information (Section 3.3.3).

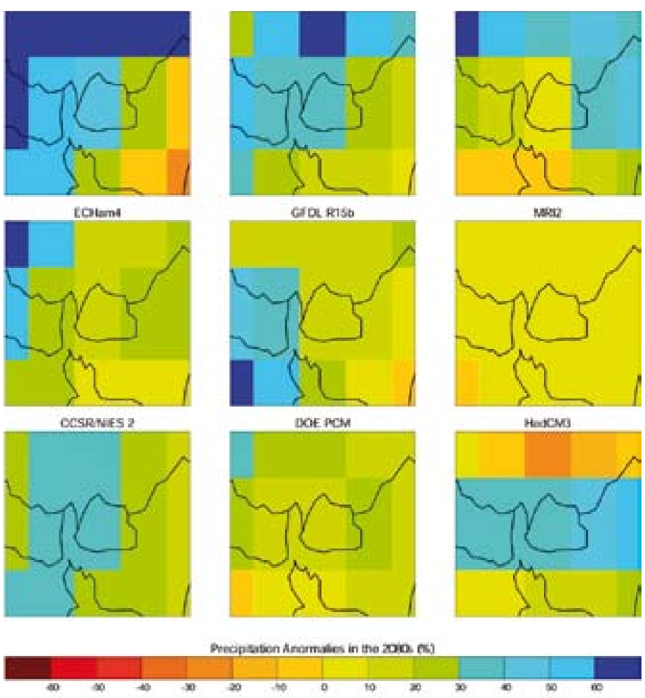


Figure 13: June-July-August (JJA) precipitation change scenarios for southeast Asia as simulated by nine GCMs forced by the SRES A2 emissions scenario for the 2080s (*Source*: AIACC, http://www.aiaccproject.org/resources/GCM/GCM_DIAG/BHUTAN.zip).

3.3.3 Downscaling GCM outputs

As discussed above, the resolution of GCM outputs has hindered V&A assessments where impacts of changes in climate, extreme events and coastal/mountainous topography are important. Therefore, outputs from GCM experiments need to be "downscaled", both spatially and temporally, for applications at a finer scale. Various downscaling techniques have been developed to serve different purposes within specific contexts of data availability and technical capacity.

To downscale GCM outputs spatially, regional climate modelling (see Section 3.2) and statistical downscaling techniques can be applied. RCMs, which typically operate at 50km × 50km resolution, use the GCM outputs as boundary conditions for a more detailed simulation of relevant processes over a limited geographic area. Statistical downscaling methods provide projections of local climate variables using GCM-simulated large-scale circulation indices under enhanced forcing and the statistical relationship between observed large-scale circulation indices and local meteorological variables for the baseline period. Statistical downscaling can usually generate projections for specific locations.

Detailed discussions on data and technical skill requirements, advantages, disadvantages and added value of using RCM outputs and statistical downscaling models for scenario development are provided in Mearns (2003) and Wilby (2004) respectively. Readers of this document are strongly advised to consult these two documents. Some of the key issues in relation to spatial downscaling are highlighted here:

(1) Any downscaling efforts, particularly a regional climate modelling approach, have to be well justified. As they are resource- and time-demanding, any decision to take on downscaling should be based on the demonstrable added-value of such an exercise. A more detailed discussion on applications where downscaling is warranted and confers added value can be found in Wilby (2004).

(2) Relatively speaking, *statistical downscaling* is less resource- and time-intensive than regional climate modelling (see Section 4.1 for an example of such tools) and therefore *might be a better option* for teams with limited time, resources and technical capacity. But the credibility of

downscaled scenario information is, to a notable extent, determined by the quality of observed climate data and the complexity of topography of the target area. Further, statistical downscaling methods usually require upper air information (commonly reanalysis data), which may be difficult to obtain or interpret for some users.

(3) *RCMs*, particularly those that can be run on a PC, are being applied in various NAI country regions (see Section 4.1). Given the limited time available for preparing national communications, it is advisable that countries make use of existing outputs from RCM experiments performed in the region, rather than running experiments under the national communication project. However when regional climate modelling is justified (i.e., scenarios with sufficient regional detail are essential to the assessment and technical capacity and resources exist for such a modelling exercise), countries are encouraged to perform RCM experiments jointly with neighbouring countries. Due to technical complications related to configuring, performing, calibrating and analysing RCM experiments, it takes a significant amount of time to produce a meaningful length of simulations[9]. Therefore, the V&A studies under the national communication should not heavily depend on RCM experiments for climate scenario development.

To downscale GCM outputs temporally, a common approach is to manipulate/perturb the parameters of stochastic weather generators so as to simulate changes in climate variability on daily to interannual time scales. Discussions on the advantages, disadvantages, and examples of applications of weather generators as a downscaling tool are provided in IPCC-TGCIA (1999) and Wilby (2004).

Figure 14 summarises the key features of data from site-specific observations, GCM outputs and climate change scenario data from different downscaling techniques.

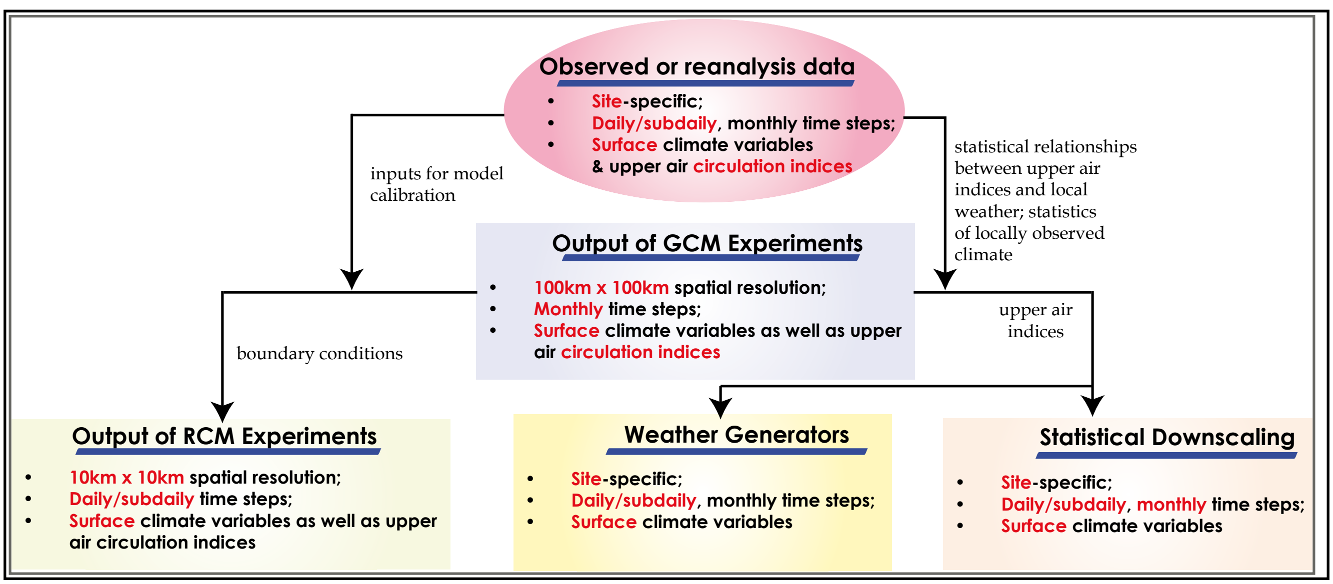


Figure 14: Characteristics of observations, GCM outputs and downscaled climate change scenarios.

[9] As a general reference, with average computing resources and skilled modellers, it takes more than one year to obtain results of a 20-year experiment.

3.3.4 Developing scenarios of extreme weather events

Although a wide range of impacts have been estimated for projected changes in mean climate conditions, the most severe impacts are expected to be brought by extreme weather events that are projected to be more intense and more frequent under a changing climate. Indeed, adaptation decision-making often requires scenario information on extreme events.

Typically, streams of daily data from GCM or RCM experiments are used for analysing changes in extreme weather events. This may prove computationally challenging for most NAI countries. As the availability of high-resolution scenarios and computing resources improves, it is hoped that the development of scenarios for extreme events will be facilitated, particularly for NAI countries. In addition, research has been undertaken to explore techniques for characterising extreme events using large scale variables which can be simulated by climate models with more confidence. For example, Goodess (2003) suggested to construct conditional damage functions (CDFs) by identifying statistical relationships between extreme events themselves and large scale air-flow indices.

Table 1 below provides an overview of estimated confidence in observed and model projected changes for extreme weather and climate events as assessed in the IPCC Third Assessment Report (TAR). Such estimates will be updated in the IPCC Fourth Assessment Report (AR4).

Table 1: Estimates of confidence in observed and projected changes of extreme weather and climate events (Cubasch *et al*. 2001)

Confidence in observed changes (latter half of the 20th century)	Changes in phenomenon	Confidence in projected changes (during the 21st century)
Likely	Higher maximum temperatures and more hot days[a] over nearly all land areas	Very likely
Very likely	Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely
Very likely	Reduced diurnal temperature range over most land areas	Very likely
Likely over many areas	Increase of heat index[b] over land areas	Very likely over most areas
Likely over many Northern Hemisphere mid- to high-latitude land areas	More intense precipitation events[c]	Very likely over most areas
Likely in a few areas	Increased summer continental drying and associated risk of drought	Likely over most mid-latitude continental interiors (lack of consistent projections in other areas)
Not observed in the few analyses available	Increase in tropical cyclone peak wind intensities[d]	Likely over some areas
Insufficient data for assessment	Increase in tropical cyclone mean and peak precipitation intensities[d]	Likely over some areas

a Hot days refers to a day whose maximum temperature reaches or exceeds some temperature that is considered a critical threshold for impacts on human and natural systems. Actual thresholds vary regionally, but typical values include 32^{0}C, 35^{0}C or 40^{0}C.

b Heat index refers to a combination of temperature and humidity that measures effects on human comfort.

c For other areas, there are either insufficient data or conflicting analyses.

d Past and future changes in tropical cyclone and frequency are certain.

Table 2 provides an overview of the relative advantages and disadvantages of various climate change scenario methods.

Table 2: Comparison of climate change scenario methods (adapted from Mearns *et al.*, 2003)

Scenario type or tool	Description/use	Advantages	Disadvantages
Direct AOGCM outputs	• Starting point for most climate scenarios • Large-scale response to anthropogenic forcing	• Information derived from the most comprehensive, physically based models • Long integrations • Data readily available • Many variables (potentially) available	• Spatial information is poorly resolved • Daily characteristics may be unrealistic except for very large regions • Computationally expensive to derive multiple scenarios • Large control run biases may be a concern for use in certain regions
High resolution/stretched grid (AGCM)	• Provides high resolution information at global/continental scales	• Provides highly resolved information • Information is derived from physically-based models • Many variables available • Globally consistent and allows for feedbacks	• Computationally expensive to derive multiple scenarios • Problems in maintaining viable parameterisations across scales • High resolution is dependent upon SSTs and sea ice margins from driving model (AOGCM) • Dependent upon (usually biased) inputs from driving AOGCM
Regional models	• Provides high spatial/temporal resolution information	• Provides very highly resolved information (spatial and temporal) • Information is derived from physically-based models • Many variables available • Better representation of certain weather extremes than in GCMs (2, 4)	• Computationally expensive, and thus few multiple scenarios • Lack of two-way nesting may raise concern regarding completeness • Dependant upon (usually biased) inputs from driving AOGCM
Statistical downscaling	• Provides point/high spatial resolution information	• Can generate information on high resolution grids or non-uniform regions (3) • Potential for some techniques to address a diverse range of variables (3) • Variables are (probably) internally consistent (2) • Computationally (relatively) inexpensive (5) • Suitable for locations with limited computational resources (5) • Rapid application to multiple GCMs (4)	• Assumes constancy of empirical relationships in the future • Demands access to daily observational surface and/or upper air data that spans range of variability • Not many variables produced for certain techniques • Dependent upon (usually biased) inputs from driving AOGCM

3.3.5 Representing uncertainties in climate scenarios

As discussed before, there are formidable uncertainties associated with climate change scenarios. For climate change scenarios derived from GCM outputs, there are four main sources of uncertainty:

Uncertainties in future greenhouse gas and aerosol emissions

Different assumptions about the evolution of the world population, global economy, technology, land use and agriculture lead to widely different trajectories of greenhouse gas and aerosol emissions. Emissions scenarios explore the uncertainties associated with emissions over the 21st century and beyond. Since the early 1990s, there have been two major sets of emissions scenarios developed through the IPCC, labelled the IS92 (Leggett *et al.*, 1992) and SRES (Nakićenović *et al.*, 2000) scenarios. A new set of scenarios is being planned for the IPCC Fifth Assessment Report (to be completed in 2012). The majority of GCM simulations for the 21st century use the IPCC SRES emissions scenarios, which are summarised in Box 2.

It is worth noting that the IPCC SRES scenarios have not only provided emissions scenarios to drive GCM experiments. Their underlying assumptions about the drivers of greenhouse gas and aerosol emissions have also been used as storylines for deriving socio-economic scenarios in CCIAV studies (e.g., in the global assessment of water scarcity, as in Arnell, 2004). Hence, the SRES scenarios have become an integrated framework for developing internally consistent climate and socio-economic scenarios required for V&A assessments and other policy analysis.

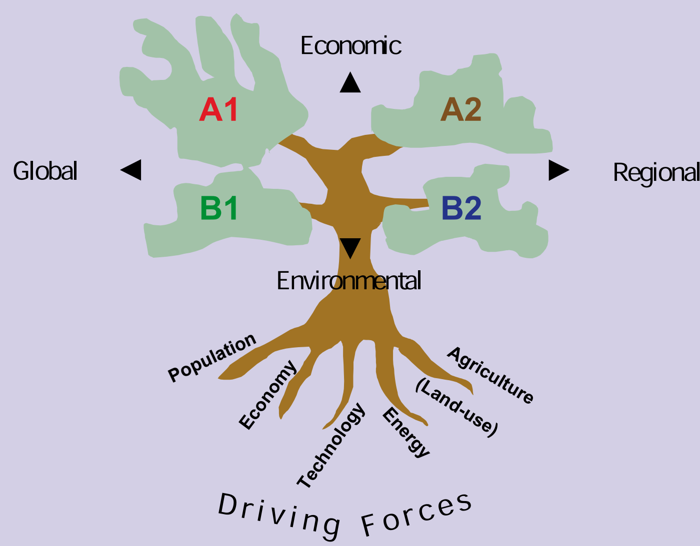
BOX 2: The IPCC Special Report on Emissions Scenarios (SRES) (adapted from Ruosteenoja *et al.*, 2003)

The SRES emissions scenarios are reference scenarios for the 21st century that seek specifically to exclude the effects of climate change and climate policies on society and the economy ("non-intervention"). The scenarios are based on a set of four narrative storylines labelled A1, A2, B1 and B2. The storylines combine two sets of divergent tendencies: one set varies its emphasis between strong economic development and strong environmental protection; the other set varies between increasing globalisation and increasing regionalisation (Nakicenovic *et al.*, 2000). The storylines can be briefly described as follows:

A1: A future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technologies. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality.

A2: A differentiated world. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth and less concern for rapid economic development.

B1: A convergent world with rapid change in economic structures, "dematerialisation" and introduction of clean technologies. The emphasis is on global solutions to achieve environmental and social sustainability, including concerted efforts for rapid technology development, dematerialisation of the economy and improving equity.



Box 2, Figure 1: A schematic representation of the SRES scenarios (Nakićenović *et al.*, 2000)

B2: A world in which the emphasis is on local solutions to achieving economic, social and environmental sustainability. It is a heterogeneous world with less rapid, and more diverse, technological change, but a strong emphasis on community.

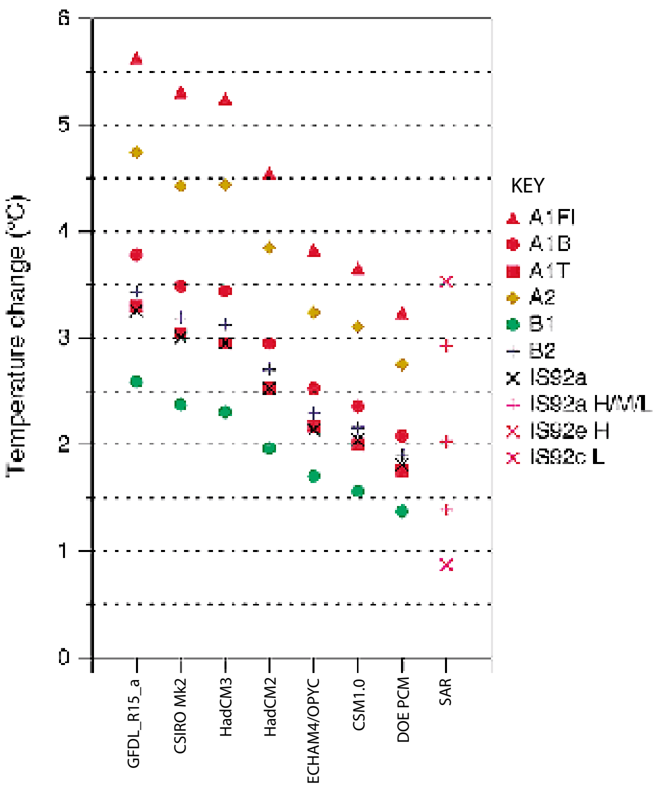


Figure 15: Changes in global mean surface temperature with respect to 1990-2100 for the SRES and IS92 scenarios. The bottom axis indicates the AOGCM to which the simple climate model is tuned. For comparison, results are also shown for the Second Assessment Report (SAR) version of the simple climate model, using SAR forcing with some of the IS92 scenarios. IS92a H/M/L refers to the IS92a scenario with climate sensitivities of 1.5°C, 2.5°C and 4.5°C respectively. Also shown are the IS92e scenario with a sensitivity of 4.5°C and the IS92c scenario with a sensitivity of 1.5°C (Cubasch *et al.*, 2001)

Although the relative likelihood of different SRES emissions scenarios has been a hotly debated subject within the scientific community, there has been no consensus. Hence, all the scenarios should typically be considered as equally likely. To account for uncertainties in emissions scenarios, it is advisable to use GCM outputs forced by a range of emissions scenarios, rather than a "single, best guess" scenario. Figure 15 illustrates the wide range of projections for global temperature change as simulated by a simple climate model under a range of different emissions scenarios.

Uncertainties in global climate sensitivity

Due to differences in the way physical processes and feedbacks are represented in different models, some GCMs simulate greater mean global warming per unit of radiative forcing than others. This is also illustrated in Figure 15 by the range of global temperature change projections simulated by the simple climate model tuned to emulate the response of different GCMs.

Model evaluation and comparison efforts to date have not found one single GCM that has proved to perform outstandingly across all regions, for all variables and for all seasons. It is therefore necessary to select those GCMs that meet as many as possible of the criteria discussed above. After analysing the skills of the GCMs (e.g., through spatial and temporal comparisons between modeled and observed climatology), focus might be given to GCMs that exhibit greater skill in reproducing key features of the regional climate regime under current conditions.

Uncertainties in regional climate changes

Different GCMs give widely different regional patterns of climate response. This has implications for the application of GCM outputs. Figure 16 (opposite) illustrates the wide range of projections for seasonal temperature and precipitation changes simulated by different GCMs in Uganda. As shown in the example, the projections differ not only in magnitude, but sometimes even in direction. It is therefore important to consider a range of GCM outputs to account for uncertainties associated with climate models.

To represent the three types of uncertainties described above, projections of global mean temperature changes from simple climate models and regional patterns of climate response simulated from GCMs are combined through a pattern-scaling technique. A detailed description of the technique and its step-by-step application is given in Lu (2002).

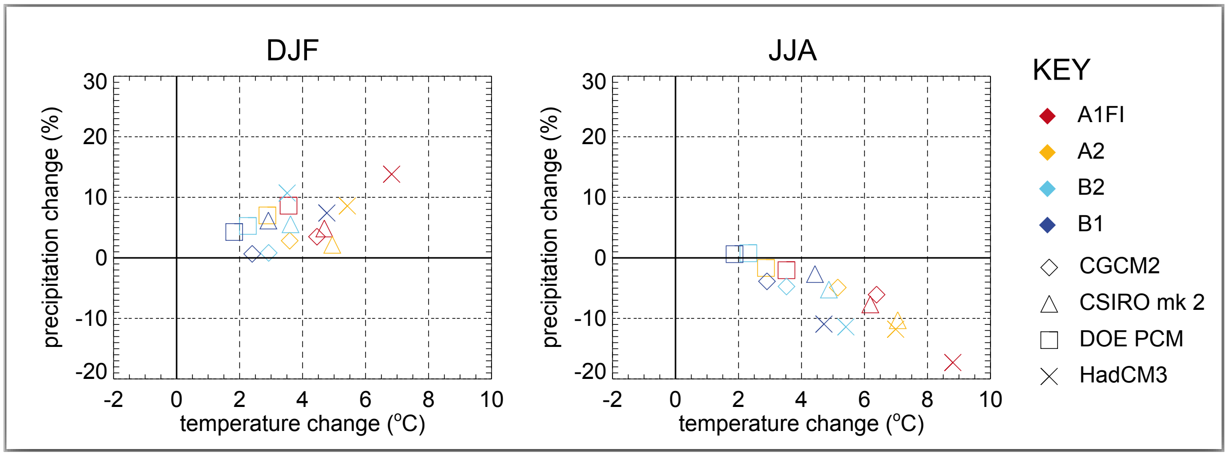


Figure 16: Projections by different GCMs of changes in seasonal temperature and precipitation by 2100 in Uganda (denoted by shapes) and under different emissions scenarios (denoted by colours) (adapted from Mitchell *et al.*, 2002)

Uncertainties associated with downscaling methods

To provide inputs for V&A assessments at regional or local scale, different techniques are employed to downscale climate change projections derived from GCM simulations. However, the selection of downscaling methods brings in another layer of uncertainty. Studies have shown significant discrepancies in projections of daily climate variables at local scale with different downscaling methods (e.g., Khan *et al.*, 2006, Wilby and Harris, 2006). When applied to V&A assessments, such discrepancies can lead to considerably different conclusions (e.g., Wilby and Harris, 2006).

3.4 Construct climate scenarios

Once the climate baseline is defined and climate change scenarios derived, climate scenarios can be developed by combining these two components.

Equations (1) and (2) illustrate how to combine baseline climate and climate change fields in a scenario for different climate variables. For variables related to the thermal state, such as temperature and various radiation indices, Equation 1 is used to define the future state from baseline data and the change field. Equation 2 is applicable for variables associated with the hydrological regime[10], such as precipitation, snowfall, humidity, soil moisture, etc.

$$X_i = \overline{X}_b + \Delta X_i \qquad (1)$$

$$X_i = \overline{X}_b \times (1 + 0.01 \times \Delta X_i) \qquad (2)$$

Where:
X_i is the value of variable X in a future year (or period) i;
X_b is the average value of variable X over the baseline period;
ΔX_i is the change in variable X in a future year (or period) i with respect to the value for baseline period.

For variables applied in Equation 1, ΔX_i is usually calculated as the difference between the model simulation for the future year (or period) *i* (X_{mi}) and the simulation for the baseline period (X_{mi}): $\Delta X_i = X_{mi} - X_{mb}$.

In Equation 2, ΔX_i is usually calculated as the percentage change between the model simulation for the future year (or period) *i* (X_{mi}) and the simulation for the baseline period:

$$\Delta X_i = \frac{(X_{mi} - X_{mb})}{X_{mb}} \times 100$$

[10] It should be noted there are cases where absolute changes in hydrological variables, instead of percentage change, need to be calculated. For example, in situations where models fail to reproduce low or zero precipitation under present-day conditions, any changes can then be infinite (if positive) or impossible (if negative) using Equation (2). In these cases, the absolute change method (i.e., Equation 1) may be applied, or some truncation method should be applied to avoid impossible outcomes. A more detailed discussion on this can be found in Mearns *et al.*, 2001.

Box 3: An example of the construction of climate scenarios using baseline data and change fields derived from GCM simulations

In this simple example, we consider a hypothetical region *R* falling within a GCM grid box *B* assuming:

June-July-August (JJA) seasonal average temperature (T) for 1961-1990 for R is observed to be 20.0^{0}C, i.e., $\overline{T}_b = 20^0$C, and average precipitation rate (P) is 3.0 mm/day, i.e., $\overline{P}_b = 3.0$mm/day.

From the GCM simulation for B, over 1961-1990, the average temperature JJA is 18.0^{0}C, i.e., $T_{mb} = 18^0$C, and the precipitation rate is 3.5mm/day, i.e., $P_{mb} = 3.5$mm/day. For the future period 2071-2100, the average JJA temperature is 23.0^{0}C, i.e., $T_{mi} = 23^0$C, and the precipitation rate is 2.5mm/day, i.e., $P_{mi} = 2.5$mm/day.

Therefore, the model-simulated change in JJA temperature over the region for 2071-2100, with respect to the baseline period 1961-1990, is $\Delta T_i = T_{mi} - T_{mi} = 23.0 - 18.0 = 5.0^0$C ; and the JJA temperature for 2071-2100 is $T_i = T_b + \Delta T_i = 20.0 + 5.0 = 25.0^0$C.

Similarly, the model-simulated change in JJA precipitation rate over the region for 2071-2100, with respect to the baseline period 1961-1990 is:

$$\Delta P_i = \frac{P_{mi} - P_{mb}}{P_{mb}} \times 100 = \frac{2.5 - 3.5}{3.5} \times 100 = -28.6$$

and JJA precipitation rate 2071-2100 is:

$$P_i = P_b \times (1 + 0.01 \times \Delta P_i) = 3.0 \times (1 - 0.286) = 2.14 \text{ mm/day}$$

It is also evident that, in relation to the observations, the GCM simulation for the baseline period 1961-1990 has a bias of -2.0^{0}C (=18.0 – 20.0) for JJA temperature and

16.7% ($= \frac{3.5 - 3.0}{3.0} \times 100\%$) for precipitation rate.

In addition, to construct multi-decadal average seasonal climate scenarios (as illustrated in Box 3), Equations 1 and 2 could also be used (with minor adjustments) to incorporate climate variability at annual or daily scale in climate scenarios. Depending on the context of the application and data availability, both observed and model-simulated climate variabilities can be incorporated. Discussions on ways to consider variability in climate scenarios are provided in IPCC-TGCIA (1999). Interested national communication teams are recommended to consult this document or to contact the National Communications Support Programme to obtain further guidance.

3.5 Documentation

As discussed in Section 2, climate scenarios created within the framework of national communications can be used for engaging stakeholders in policy dialogues and V&A assessments. To facilitate the appropriate interpretation and application of the scenario information, particularly for applications beyond the lifetime of the national communication process, it is essential to document the following details of the scenarios.

3.5.1 Sources of data and methods used for scenario development

Sources of data and the methods used for defining the climate baseline and deriving climate change scenarios should be clearly documented. This is important for the following reasons:

(1) Potential users need information on the underpinning of data sources and methodology to make judgements about the credibility of the scenario information as a basis to decide on its use;
(2) Data sources and methods ultimately determine the quality of the scenario data, hence the policy relevance of any V&A analyses applying them;
(3) Clear description of data sources and methods facilitates comparisons between studies applying (new) climate scenarios and those using earlier scenario information;
(4) Last but not least, data sources and methods reveal a lot about the context of the scenarios and help enable their interpretation.

3.5.2 Uncertainties

It is important to explicitly indicate the range of uncertainties represented in the climate scenarios. For instance, if scenarios are derived from a few GCM experiments forced by emissions scenarios which project middle-range climate change for the region of concern, it is important to point this out and encourage consideration of a wider range of possible changes for policy-oriented risk analyses. Representativeness of climate scenarios developed with relation to the wider range of uncertainties should also be explicitly reported. With such information, potential scenario users will be able to gauge the overall scale of climate risk as implied by the scenario information.

3.5.3 Limitations

NAI countries have reported on chronic issues related to data and technical capacity to support climate change-related activities (e.g., UNFCCC, 2005). Therefore, in most countries, researchers developing climate scenarios will continue to have to confront these challenges during the SNC process. It is critical that *all* the limitations and caveats associated with climate scenarios are explicitly documented. Typical limitations are summarised as follows.

(1) Due to incomplete observational records, *proxy data* (e.g., data from a neighbouring station or weather generator used to fill in the gaps in the record, etc.) have to be used;
(2) Due to time and resource constraints, uncertainties related to emissions scenarios and climate models are not adequately represented in scenarios;
(3) Coarse spatial and temporal resolutions, or the "wrong" time frame of climate scenarios, do not match the requirements of policy-oriented applications.

Although it does not resolve the limitations, explicit documentation could be helpful to inform potential users and enable them to place scenario information into proper perspectives. Good reporting and documentation will also help highlight major knowledge and/or data gaps to individual government agencies and international bodies. This is an important first step in addressing unresolved information needs.

3.5.4 Guidance for the application of scenarios

Having the potential scenario users in mind, clear guidance should be provided on: i) how to interpret the scenarios, particularly with relation to the uncertainties and limitations, and ii) possible applications at national, sub-national and local levels. It is particularly important to make clear the intended application of the scenarios. For example, scenarios of 30-year, average annual precipitation for the end of the century would be of little use for a CCIAV assessment looking at the risk of a local watershed failing to supply water for irrigation and domestic uses during the dry season within a time frame of 10-15 years from now.

Documentation on climate scenarios can be summarised in the section of the V&A chapter of the national communication. National communication teams might also consider publishing a stand-alone document as part of the national communication outputs for wider dissemination. The UK Climate Impacts Programme (UKCIP) Climate Scenarios (Hulme *et al.*, 2002) can be used as an example for developing such a stand-alone document and disseminating national climate scenarios. Details on UKCIP climate scenarios can be found at http://www.ukcip.org.uk/scenarios/ukcip02/documentation/ukcip02_scientific_report.asp. National climate scenarios have also been developed and documented in Australia[11], Canada[12] and Finland[13].

Table 3 overleaf provides a generic template for documenting data sources and methods used, uncertainties and guidance for intended scenario applications within and beyond SNCs.

[11] See details at http://www.dar.csiro.au/impacts/future.html
[12] See details at http://www.cics.uvic.ca/scenarios/
[13] See details at http://www.ymparisto.fi/default.asp?contentid=84906&lan=EN

Table 3: Template for documenting data sources and methods used for climate scenario development

	Climate baseline	Climate change scenarios
Data Sources (To specify variables for which data are obtained, length of the data series, spatial and temporal resolutions)	• Station observations (specify the stations and agencies collecting and archiving observations and quality assurance/ quality control procedures applied) • Supranational or global data sets • Reanalysis data or other model output • Direct use of climate model outputs	• Synthetic scenarios (details on the arbitrary changes adopted and the justifications, if any) • Analogue scenarios (justifications for each analogue selected) • Model outputs-based scenarios (underlying emissions scenarios and climate model outputs
Methods (While models and tools are used, details need to be provided on the calibration and validation process applied)	• Direct use of observed data • Weather generators to fill gaps in data series and simulate natural variability	• Use of analogue climate records • Direct use of model outputs (specify the spatial and temporal resolution) • Statistical downscaling • Dynamic downscaling
Uncertainties (To specify which uncertainties are represented in constructed climate scenarios)		• Uncertainties in greenhouse gas emissions • Uncertainties in GCMs • Uncertainties in RCMs • Uncertainties in downscaling methods
Limitations (To flag limitations and caveats related to gaps in observational- and model-based data, constraints in scenario analyses, etc)	• Limitations with observed data (e.g., short series, gaps in records, etc) • Limited unforced climate model outputs for analysing natural variability	• Limited range of uncertainties represented • Data only available for undesirable time horizon • Inadequate spatial resolution • Limited information on extreme events • Limited data for a wide range of climate variables
Guidance for applications (To provide general guidance on the appropriate uses of the scenario data)	• Measurement of natural variability of regional climate • Reference for measuring future changes	• Communication of climate change to stakeholders • Sensitivity analyses • Policy-oriented V&A assessments

4 MODELS, TOOLS AND DATA SOURCES

This section outlines commonly used models, tools, data sources and guidance materials that exist in the public domain. NAI countries can use these resources, free of charge, for climate scenario development. New models, tools, data sources and guidance documents will be added to the NCSP's knowledge network on V&A (http://www.va-network.org) as they become available.

4.1 Models and tools

The following models and tools have been widely used to generate climate scenarios.

4.1.1 Model for the Assessment of Greenhouse gas Induced Climate Change/Scenario GENerator

The Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) is a simple climate model. It uses a series of reduced-form models to emulate the behaviour of fully three-dimensional, dynamic GCMs. MAGICC rapidly calculates the annual-mean global surface air temperature rise and global-mean sea level change under selected emissions scenarios and model parameters. Hence, it can be used to explore the global climate and sea level implications of emissions scenarios and uncertainties associated with model parameters. MAGICC can be used on its own, but has also been designed to be used in conjunction with a global and regional SCENario GENerator (SCENGEN).

SCENGEN is *not* a climate model; rather, it is a database that contains the results of a large number of GCM experiments, observed global and regional climate data sets and simple analytical modules. MAGICC/SCENGEN converts scenarios of greenhouse gas and sulphur dioxide emissions into estimates of global-mean surface air temperature and sea level changes, and then into descriptions of future changes in regional climate.

MAGICC has been used by the IPCC in their various assessments. SCENGEN has not been officially used by the IPCC, but nearly all the data sets within SCENGEN have been used and assessed in different IPCC assessments.

MAGICC/SCENGEN provides an accessible, low cost and versatile tool for generating regional climate scenarios for any area of the world. There are, however, a number of major limitations to be considered when using MAGICC/SCENGEN:

(1) Its reliance on pattern-scaling methods to combine GCM regional patterns of climate change with global projections from MAGICC;
(2) The coarse resolution of resulting regional scenarios (the current version has a spatial resolution of 5 degrees longitude × 5 degrees latitude);
(3) Exclusion of climate variables other than mean temperature and precipitation.

The current version of MAGICC/SCENGEN, together with a technical manual and a users' guide, is available at http://www.cgd.ucar.edu/cas/wigley/magicc/index.html. A workbook on an earlier version is available at http://ncsp.undp.org/site_documents/magicc_scengen_workbook1.pdf.

The MAGICC/SCENGEN software and related documentation are currently being updated[14]. It is expected to be made available to NAI countries in 2007 in conjunction with the publication of the IPCC AR4.

4.1.2 Statistical DownScaling Model

The Statistical DownScaling Model (SDSM) is a Windows-based, decision support tool that allows rapid development of *single-site, ensemble scenarios* of *daily* weather variables under current and future regional climate forcing. The model is based on the statistical relationship between local weather variables (or *predictands*, required by impact studies) and large-scale circulation indices (or *predictors*, which are often more reliably simulated by GCMs).

To facilitate the application of SDSM in site-specific climate scenario development, the Canadian Institute for Climate Studies developed a portal[15] that provides free access to SDSM predictor variables. Daily GCM outputs for both current and future time periods, as well as reanalysis data developed by US National Centers for Environmental Prediction can be extracted for a user-specified grid box. These datasets can be directly used for model calibration and scenario development within SDSM for any land area (see Figure 17 overleaf for an example screen for Africa).

[14] Under the auspices of the NCSP, with financial support from the US Environmental Protection Agency.

[15] http://www.cics.uvic.ca/scenarios/sdsm/select.cgi

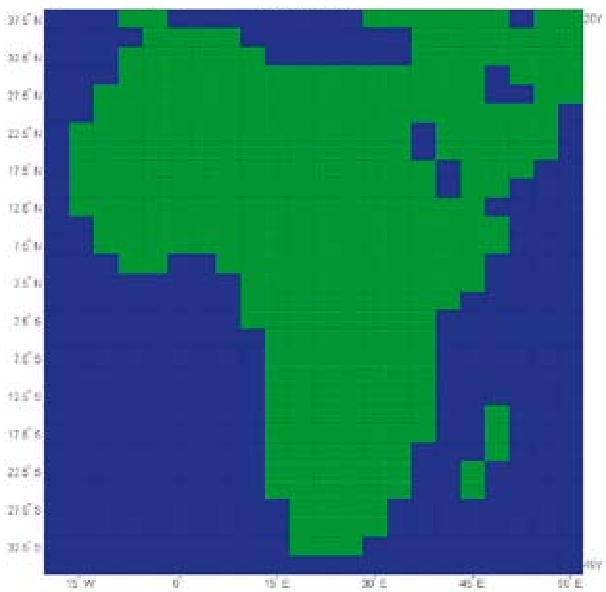


Figure 17: Individual grid points in Africa for which reanalysis and GCM predictor variables are available in SDSM format from the Canadian Institute for Climate Studies website.

SDSM provides a useful technique to generate scenarios at single site and at daily time step, which are consistent with data requirements for a large number of impact assessments. However, like all other regression-based modeling tools, SDSM should not be used uncritically as a "black box". In particular, due to its unpredictability, daily precipitation amounts at individual sites are the most problematic to downscale. It is, therefore, important to combine the following efforts with the application of SDSM:

(1) Rigorously evaluate candidate predictor-predictand relationships using independent data;
(2) Apply local knowledge to identify a sensible combination of predictors;
(3) Using predictor data from multiple GCM experiments to represent uncertainty in local scenarios associated with large-scale forcing.

It should also be noted that running the SDSM requires at least 20 years of good-quality, observed daily weather data.

The SDSM software, together with example data sets and a user manual, is available at http://www.sdsm.org.uk. The model is currently being upgraded to include better visualisation of model outputs, as well as new tools for extreme event frequency analyses and model verification.

4.1.3 Providing REgional Climates for Impact Studies

Providing Regional Climates for Impact Studies (PRECIS) is a flexible and easy-to-use RCM. It was developed by the Hadley Centre for Climate Prediction and Research of the UK Met Office for the generation of regional climate scenarios.

To date, PRECIS has been, or is being, applied in the following countries and sub-regions:

- South Asia (Pakistan, India, Nepal, Bhutan, Bangladesh, Sri Lanka);
- China;
- South-east Asia;
- southern South America (Argentina, Uruguay, Chile, Brazil);
- northern South America (Brazil, Peru, Ecuador, Venezuela, Suriname, Guyana, Colombia);
- the Caribbean;
- Central America;
- West Africa;
- Eritrea; and
- Southern Africa.

Details of the scientists and institutions leading PRECIS experiments in these regions can be found at http://www.precis.org.uk/worldwide.html.

Although PRECIS has the advantages of being flexible and easy-to-use, the human and computational resources required to apply the model are not insignificant. When considering the use of PRECIS, the following factors need to be taken into account (Jones *et al.*, 2004):

(1) In the standard PRECIS set-up, there is an implicit *maximum resolution of 25 km*; thus smaller countries or regions (e.g., islands) will not be resolved within the model;
(2) In order to validate model outputs at the local level, it is desirable to have *good observations* of the climate relevant to the region. This may prove problematic for some countries;
(3) In addition to the basic computing resource of *one or more fast PCs with substantial storage capacity*[16], it is useful to have a *reliable power supply*. It is also necessary to have the *expertise* to maintain hardware and support systems;

[16] NAI countries (e.g., in the Caribbean) have been experiencing major difficulties with storage space for the large volume of interim and final outputs from the PRECIS experiments.

(4) Running the model and processing and interpreting results from the PRECIS experiments requires the *dedicated time of scientists* with relevant skills and experience;
(5) PRECIS experiments *take several months to run*[17], so they cannot be used to provide instant climate scenarios;
(6) PRECIS experiments require lateral boundary conditions from GCMs. Currently users are limited to *boundary conditions from the Hadley Centre GCM simulations*[18]. Therefore, uncertainty due to GCMs cannot be explored through the use of PRECIS experiment outputs.

A handbook on the use, advantages and limitations of PRECIS is available at http://www.precis.org.uk/docs/PRECIS_Handbook.pdf. General information on the model, new developments, and technical updates can be found on the PRECIS website http://www.precis.org.uk.

4.2 Data sources

This section provides a list of publicly available data sources that could be used for climate scenario development.

4.2.1 Data for defining the baseline climate and/or validating GCM performance

The following data sets can be used to, among others, define baseline climatic conditions and validate the GCM skills for reproducing spatial (gridded data sets) and temporal (time series data) patterns of key climate variables under current climate. The first three data sets listed in this section are produced by the Tyndall Centre for Climate Change Research (http://www.tyndall.ac.uk). The reanalysis data is produced by the National Centers for Environmental Prediction (US) and the GCM control run outputs by the individual modelling centres indicated.

10' global monthly climatology for 1961-1990

This is a 10-minute latitude/longitude data set of mean monthly surface climate over global land areas, excluding Antarctica. The climatology includes eight climate variables – precipitation, wet-day frequency, temperature, diurnal temperature range, relative humidity, sunshine duration, ground frost frequency and windspeed – and was interpolated from a data set of station means for the period 1961-1990.

This data set would be particularly useful for spatial applications, such as vulnerability zoning or mapping over a large area/region. However since it is a 30-year average climatology, it does not allow the analysis of inter-annual or intra-annual variability.

Reference on how the data set was constructed, documentation on its use and the actual data sets are available at http://www.cru.uea.ac.uk/cru/data/tmc.htm.

0.5^0 global time-series climate observations for 1901-2002

This data set comprises 1224 monthly grids of observed climate for the period 1901-2002, covering the global land surface at 0.5^0 resolution. There are nine climate variables available: daily mean, minimum and maximum temperature, diurnal temperature range, precipitation, wet-day frequency, frost-day frequency, vapour pressure and cloud cover.

This data set can be used for applications where inter-annual variability in climate elements is important, e.g., to examine the relative contributions to variations in crop production from weather variability and changes in management practices in order to determine the underlying causes of agricultural vulnerability in a region. However, given its coarse spatial resolution (0.5^0), this data set may not be adequate to capture the influence of complex topographic features (e.g., mountains) or landscapes (e.g., lakes, coastal lines) on a small-scale climate.

Documentation on the development, updates and general guidance for the use of, and access to, this data set is available at http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_1.html.

It is worth noting that these publicly available global data sets over historic periods are processed from observations obtained from a global network of stations. Their accuracy and applicability for a particular region are dependent on the validity of the algorithms used to interpolate and aggregate observational data from weather stations. It is, therefore, advisable to use locally observed and processed data to the extent possible.

Country level monthly time series for 1901-2000

This data set includes the 20th-century climate for 289 countries and territories using nine climate variables: cloud cover, diurnal temperature range, frost-day frequency, daily minimum temperature, daily mean temperature, daily maximum temperature, precipitation, wet-day frequency and vapour

[17] Considering the possible complications in configuring the experiments, which involves preparation of data sets for defining initiation and boundary conditions, it could take significantly longer than several months to obtain results.

[18] Efforts are being made to provide boundary conditions from other GCMs. See http://www.precis.org.uk/obtain.html for details.

pressure. Details on the development and update of this data-set, and information on how to access the data can be found at http://www.cru.uea.ac.uk/~timm/cty/obs/TYN_CY_1_1.html.

Reanalysis data

The Physical Sciences Division of the Earth System Research Laboratory, which is an office of the Oceanic and Atmospheric Research of the US National Oceanic and Atmospheric Administration, has produced a set of reanalysis data (Kalnaya *et al*., 1996). These data sets include six-hourly observations of daily and monthly averages for numerous meteorological parameters. They generally extend back from the present day to 1948 and cover the entire globe. For a full description of the datasets (including caveats), users should consult http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html.

The six-hourly observations and daily averages can be downloaded from the Climatic Research Unit website[19], http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html.

Outputs of GCM control runs

As discussed in earlier sections, outputs from multi-century, unforced GCM simulations can be used to analyse natural multi-decadal climate variations. Outputs from unforced GCM experiments (i.e., control runs) assessed by the IPCC AR4 have been achieved and made available from the IPCC DDC. They contain simulations conducted with 15 different GCMs. Data sets and related documentation can be found at http://www.mad.zmaw.de/IPCC_DDC/html/SRES_AR4/index.html.

4.2.2 Climate model data for deriving climate change scenarios

Direct outputs from GCM experiments

The IPCC DDC hosts three sets of outputs from GCM experiments, labelled IS92 (forced by the IS92a emissions scenario), SRES TAR (experiments conducted in conjunction with the preparation of the IPCC TAR and forced by the SRES emissions scenarios) and SRES AR4 (experiments conducted in conjunction with the preparation of the IPCC AR4 and forced by the SRES emissions scenarios), respectively.

[19] These data sets can be accessed free of charge, but users are required to acknowledge the producers and include the following text in SNC documents and other publications using the data sets: NCEP reanalysis data were provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA.

Table 4 summarises the SRES-forced AOGCM projections available at the DDC. Details on the experiments, and the actual data sets, can be accessed from http://www.mad.zmaw.de/IPCC_DDC/html/ddc_gcmdata.html.

GCM outputs from the DDC site include monthly outputs for a wide range of climate variables, with the exception of a few experiments for which daily or six-hourly outputs are available (Table 4). These data sets are provided in a rather "raw" format, thus they require further processing before being used by impact assessors.

Table 4: SRES-forced AOGCM model projections available from the DDC (December 2006): (a) experiments assessed by the IPCC TAR; (b) experiments assessed by the IPCC AR4. Experiments with underlined SRES scenarios denote that data are available from the DDC.

(a)

Centre	Acronym	Model	Forcing SRES emissions scenarios						Additional data
Max Planck Institute für Meteorologie	MPI-M	ECHAM4/OPYC3				A2		B2	6-hourly data (local access)
Hadley Centre for Climate Prediction and Research	HCCPR	HADCM3		A1F1		A2 A2b A2c	B1	B2 B2b	
Commonwealth Scientific and Industrial Research Organisation, Australia	CSIRO	CSIRO-Mk2	A1			A2	B1	B2	
National Center for Atmospheric Research	NCAR	NCAR-CSM				A2			
		NCAR-PCM	A1B			A2		B2	
Geophysical Fluid Dynamics Laboratory	GFDL	R30				A2		B2	
Canadian Centre for Climate Modelling and Analysis	CCCMA	CGCM2				A2 A2b A2c		B2 B2b B2c	Daily data (re-mote access)
Centre for Climate System Research/National Institute for Environmental Studies	CCSR/NIES	CCSR/NIES AGCM + CCSR OGCM	A1	A1F1	A1T	A2	B1	B2	

(b)

Centre	Acronym	Model	Forcing SRES emissions scenarios		
Beijing Climate Centre	Bcc	CM1	A2	A1B	
Bjerkness Centre for Climate Research	BCCR	BCM2.0	A2	A1B	B1
Canadian Centre for Climate Modelling and Analysis	CCCMA	CGCM3 (T47 resolution)	A2	A1B	B1
		CGCM3 (T63 resolution)		A1B	
Centre National de Researches Météorologiques	CNRM	CM3	A2	A1B	B1
Commonwealth Scientific and Industrial Research Organisation, Australia	CSIRO	Mk3.0	A2	A1B	B1
Max Planck Institute für Meteorologie	MPI-M	ECHAM5-OM	A2	A1B	B1
Meteorological Institute, University of Bonn Meterorological Research Institute of KMA Model and Data Group at MPI-M, Germany	MIUB METRI M&D	ECHO-G	A2	A1B	B1
Institute of Atmospheric Physics	LASG	FGOALS-g1.0	A2	A1B	
Geophysical Fluid Dynamics Laboratory	GFDL	CM2.0	A2	A1B	B1
		CM2.1	A2	A1B	B1
Goddard Institute for Space Studies	GISS	AOM	A2	A1B	
		E-H	A2	A1B	
		E-R	A2	A1B	B1
Institute for Numerical Mathematics	INM	CM3.0	A2	A1B	B1
Institut Pierre Simon Laplace	IPSL	CM4	A2	A1B	B1
Meteorological Research Institute	MIROC	MIROC3.2 hires	A2	A1B	
		MIROV-->		A1B	B1
National Centre for Atmospheric Research	NCAR	PCM	A2	A1B	B1
		CCsM3	A2	A1B	B1
UK Met. Office	UKMO	HadCM3	A2	A1B	B1
		HadGEM1	A2	A1B	B1

Processed and analysed GCM outputs

Considerable efforts have been made to process the vast volume of GCM outputs to make them easier to use in V&A assessments. The processed data sets can be grouped into the following:

Regional level

The IPCC produced a full set of regional projections based on the SRES TAR GCM experiments. Seasonal[20] temperature and precipitation projections under the four SRES marker scenarios (i.e., A1FI, A2, B2 and B1), with seven GCMs for the 2020s, 2050s and 2080s, are provided for 32 world regions (Figure 18) (Ruosteenoja *et al.*, 2003). Both the actual data and a set of scatter plots showing the range of projections for a specific region are available from http://ipcc-ddc.cru.uea.ac.uk/sres/scatter_plots/scatterplots_region.html. Figure 19 (opposite) presents an example of the scatter plots for the 2020s in Western Africa.

The full report documenting these regional projections is also available online at http://ipcc-ddc.cru.uea.ac.uk/sres/scatter_plots/scatter_plot_report.pdf.

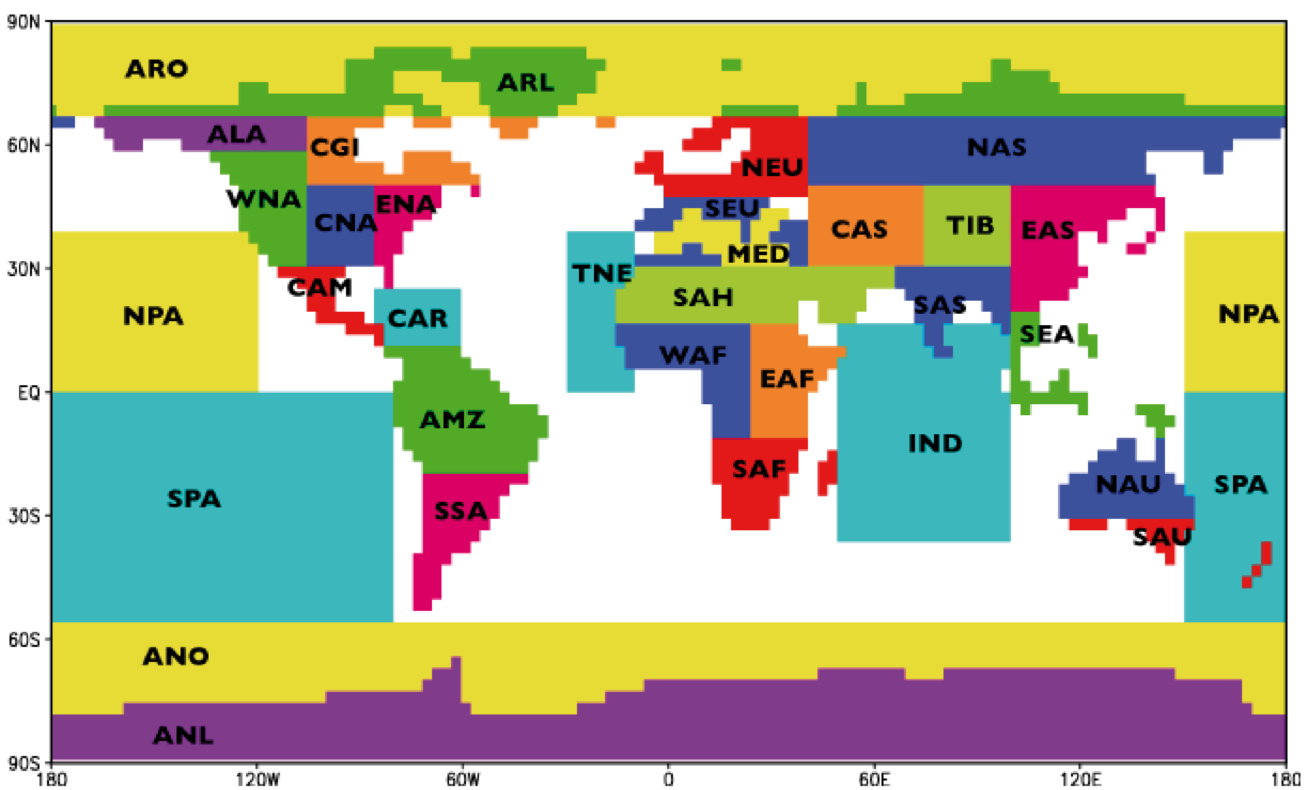


Figure 18: World regions for which seasonal climate change projections are available from the IPCC DDC.

[20] The seasons referred to in this document are in standard terms. For a particular region, these may not coincide with, for example, growing or wet seasons.

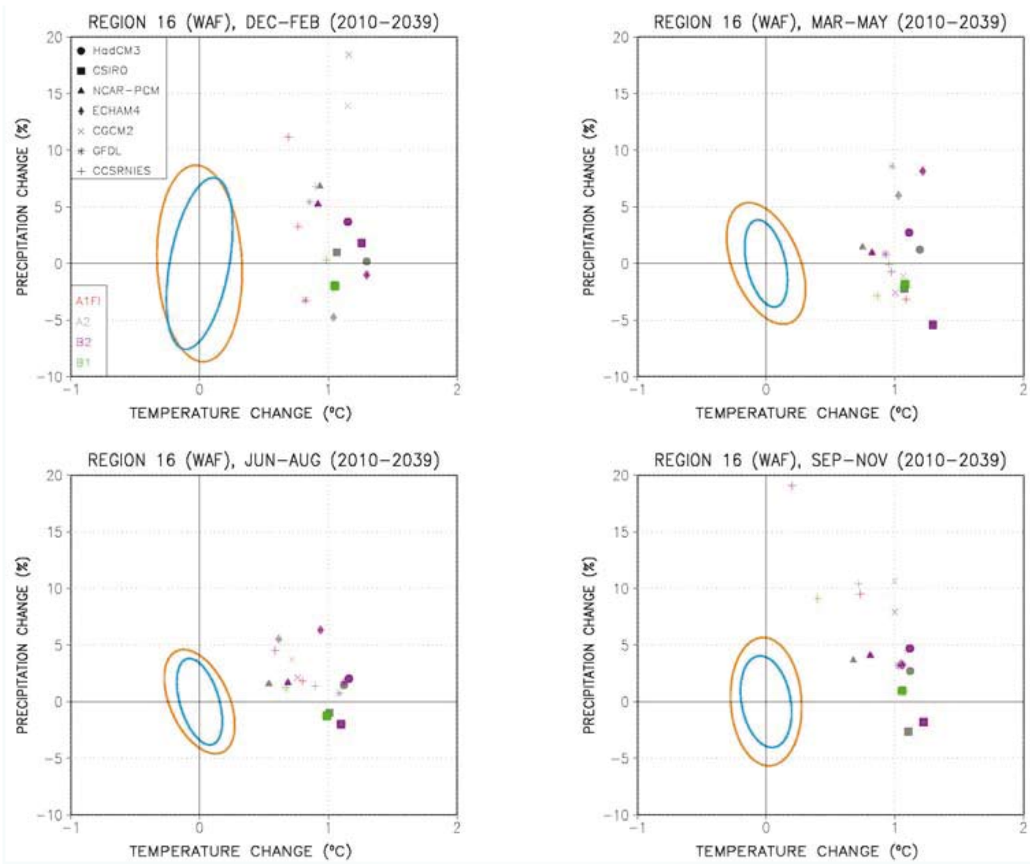


Figure 19: Scatter plot of seasonal temperature and precipitation change projections under a range of emissions scenarios, and simulated by different GCMs, for 2020s in the Western Africa region. Each scatter point represents a single, model-simulated temperature/precipitation response to one forcing scenario. The emissions scenario is depicted by the colour of the point, and the shape of the symbol defines the model. Also shown in ovals centred on the origin are the 95% Gaussian contour ellipses of the natural internal tridecadal variability of temperature and precipitation, derived from unforced 1000-year AOGCM runs performed by CGCM2 (orange) and HadCM3 (blue) (Ruosteenoja *et al.*, 2003).

Sub-regional level

A set of sub-regional level climate change projections derived from SRES TAR GCM experiments was made available through the AIACC project (http://www.aiaccproject.org). The projections are produced by extracting data from the GCM grids for geographic windows covering selected AIACC regional study areas, namely: sub-Saharan West Africa, Miombo Region, Sri Lanka, Indonesia and Philippines, Western China, Bhutan, Indian Ocean, Costa Rica, Argentina, Mexico and Northern Africa. They are available as scatter plots of seasonal temperature and precipitation projections for the 2080s, under SRES A2 and B2 emissions scenarios and simulated by nine GCMs. The scatter plots are available at http://www.aiaccproject.org/resources/GCM/GCM.html.

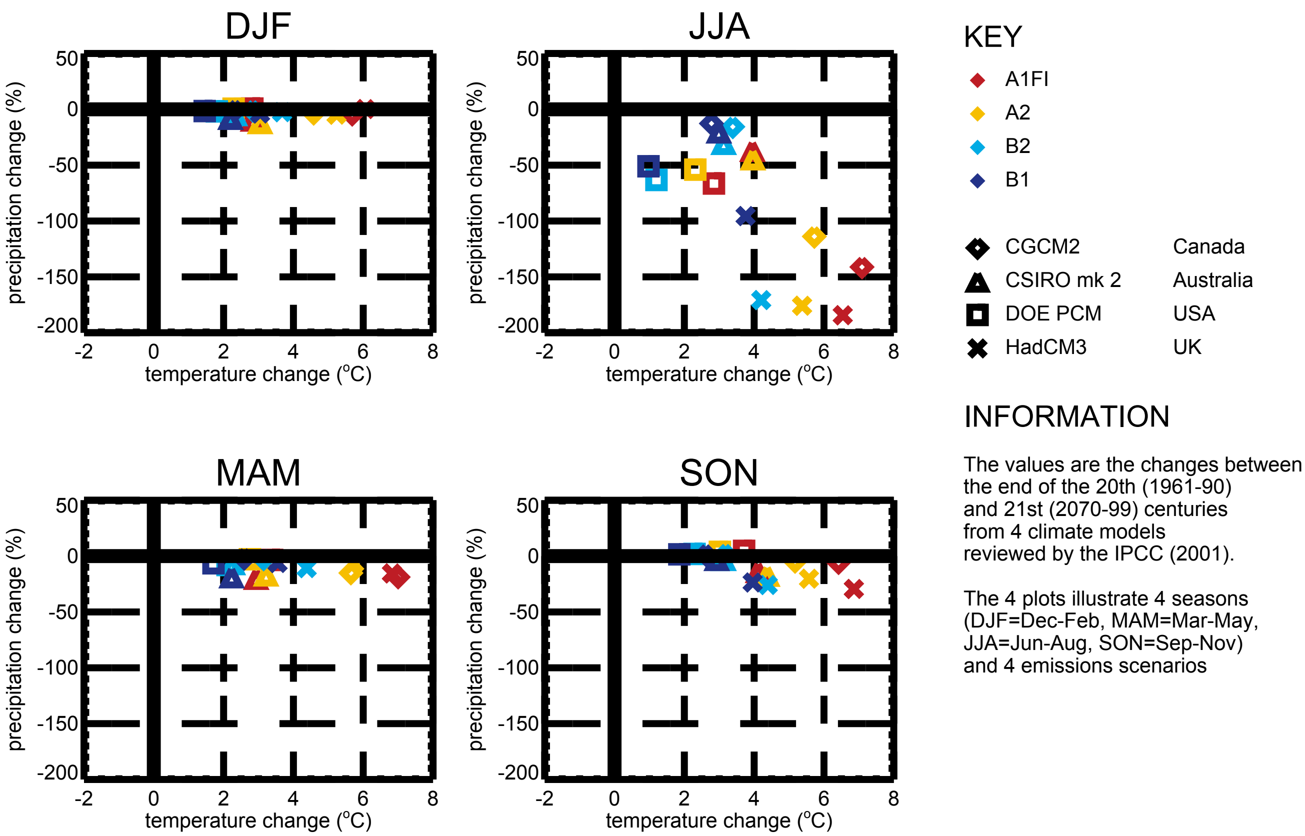


Figure 20: Changes in seasonal temperature and precipitation for the 2080s for Botswana, as simulated by nine different GCMs and forced by the SRES A2 and B2 emissions scenarios (Mitchell *et al.*, 2002)

Country level

The Tyndall Centre for Climate Change Research (UK) developed a series of country-level climate projections for the 2080s. These projections include seasonal changes in mean temperature and precipitation amount as simulated by nine GCMs and forced by the SRES A2 and B2 emissions scenarios. Both scatter plots and numerical data are available at http://www.cru.uea.ac.uk/~timm/climate/scatter/TYN_CY_2_0.html. Figure 20 provides an example of the scatter plots of climate change projections for Botswana.

It is worth noting that one should treat GCM-derived, national-level scenarios with caution, especially in cases of small countries. With the current GCM spatial resolution, island countries may be represented as ocean and countries represented by single grid boxes in a GCM. Modellers regard AOGCM projections as more robust at sub-continental scale.

District level

Under the Global Environment Facility/World Bank/Centre for Environmental Economics and Policy in Africa (GEF/WB/CEEPA) project, Climate Change and Agriculture in Africa, the University of Colorado produced climate data sets for Africa and the Middle East at district level. Data are available for changes in decadal-average monthly temperature and precipitation up to 2100, with respect to the 1961-1990 average as simulated by the Canadian GCM (CGCM) under the SRES A2 emission scenario (Kenneth Strzepek and Alyssa McCluskey, 2006). These data sets can be used free of charge by NAI national communication teams[21].

Gridded data sets

The Tyndall Centre also produced a gridded data set of modelled monthly climate projections. The data set comprises projections for 2001-2100, covering the global land surface at 0.5° resolution, for five variables: cloud cover, diurnal temperature range, precipitation, temperature and vapour pressure. Information on this data set and how to access it can be found at: http://www.cru.uea.ac.uk/~timm/grid/TYN_SC_2_0.html.

GCM outputs for generating site-specific scenarios

As indicated above, the Canadian Institute for Climate Studies portal provides daily outputs from the Hadley Centre GCM and the CGCM. GCM outputs derived from this site can be directly used to run the Statistical DownScaling Model (SDSM) described in Section 4.1. For more information, go to: http://www.cics.uvic.ca/scenarios/sdsm/select.cgi.

RCM data output

The Hadley Centre RCM, PRECIS, described in Section 4.1, has been used by a number of NAI countries. In particular, the Cuban Institute of Meteorology has performed PRECIS simulations and developed facilities to distribute the results for Central America and the Caribbean region (Figure 21). By specifying the area of interest and the characteristics of the required scenario data, users can easily obtain outputs from the PRECIS simulations. It is hoped that, with more resources becoming available, more regional centres will be able to provide similar online access to PRECIS outputs.

Figure 21: Online interface for extracting results of PRECIS experiments (http://precis.insmet.cu/Precis-Caribe.htm)

[21] The data producers are unable to offer any technical assistance on the accessing and application of these data sets. National communication teams interested in using the data should contact the NCSP team (ncsp@undp.org) for details about how to access the data and advice on using data sets.

4.3 Guidance documents

The IPCC TGICA has developed a set of guidance documents on the development of scenarios (including climate scenarios) and their application in impact studies (http://ipcc-ddc.cru.uea.ac.uk/guidelines/index.html). Although experts engaged in developing climate scenarios for national communication projects would benefit from reading all these documents, the following are of particular relevance to climate scenario development and application:

4.3.1 Guidelines on the use of scenario data for climate impact and adaptation assessment (IPCC-TGCIA, 1999)

This document offers general guidance on the interpretation and application of scenario data, including climate scenarios, in impact and adaptation assessments. It also provides user support for the IPCC DDC. The document is available online at http://ipcc-ddc.cru.uea.ac.uk/guidelines/ggm_no1_v1_12-1999.pdf.

An updated version of these guidelines is being prepared and will be made available on the TGICA website when complete.

4.3.2 Guidelines on the use of climate scenarios developed from regional climate model experiments (Mearns et al., 2003)

This guidance document provides background information on high resolution climate scenarios and descriptions of procedures for their evaluation, development and application. Recommendations are also provided for when and how to use such scenarios. Although overview material on all downscaling or regionalisation methods is presented, this document focuses on scenarios derived from RCM outputs. The document is available online at http://ipcc-ddc.cru.uea.ac.uk/guidelines/dgm_no1_v1_10-2003.pdf. Experts considering developing climate scenarios from RCM outputs are strongly advised to consult this guidance material.

4.3.3 Guidelines on the use of climate scenarios developed from statistical downscaling methods (Wilby et al., 2004)

This guidance document provides background material and a general description of the different statistical downscaling techniques, key assumptions and limitations to their use. It also advises users to consider a set of broader questions when deciding upon the downscaling approach. A worked case study is also included in the guidelines.

The document is available online at http://ipcc-ddc.cru.uea.ac.uk/guidelines/dgm_no2_v1_09_2004.pdf. Experts considering applying statistical downscaling techniques for climate scenario development are strongly advised to consult these guidelines.

5 KEY MESSAGES

To summarise, it is helpful to note the following key points when considering the development of climate scenarios for national communication V&A assessments:

- Climate scenarios constitute a major part of V&A assessment under the SNC: as direct inputs for V&A assessments, as information serving public education about expected climate change, and as a tool to engage stakeholders in policy dialogue, both within and beyond the SNC process;

- Consultation with the key potential end-users of the scenarios, such as researchers, resource managers and public and private decision-makers, is very important at various critical stages of scenario development (e.g., scoping, selection of methods/tools, presentation of results);

- Before embarking on a "fishing expedition" for data, models and tools, it is strongly advisable to allocate time to define clearly the scope of the climate scenario information needed within the framework of the SNC;

- Communication and close collaboration with groups involved in developing non-climate scenarios (e.g., scenarios of sea level and other environmental and socio-economic variables) is essential for ensuring consistency among different scenario components. This is because the vulnerability of a sector/system to climate change is also conditional on other environmental and socio-economic stresses. Therefore, policy-oriented V&A assessments require the integration of climate and non-climate scenarios;

- Technical, financial, data and time constraints all have to be considered when selecting the methods and tools for constructing scenarios;

- While working with GCM outputs, it is important to assess model skills and/or biases for the intended target region and variables of interest;

- Avoid time and resource-intensive options if simpler approaches can serve the purpose;

- Detailed documentation on how the scenarios have been constructed and on their intended applications and limitations, is as important as the scenarios themselves. If done properly, documentation helps ensure greater transparency of the methods and provides the basis for a potentially wide distribution and application of the scenarios, far beyond the lifetime of the SNC;

- To facilitate the improvement of data provision, national communication experts have a responsibility to provide feedback to modelling centres and/or data service agencies on the use of their products, as well as any requests to meet future information needs.

GLOSSARY OF TERMS[22]

Adaptation

Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including *anticipatory* and *reactive* adaptation, *private* and *public* adaptation, and *autonomous* and *planned* adaptation.

Climate

Climate in a narrow sense is usually defined as the "average weather", or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of years. The classical period is three decades, as defined by the World Meteorological Organization. These quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the UNFCCC, which defines climate change as *"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"*.

Climate model

A numerical representation of the climate system based upon the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity (i.e., for any one component or combination of components a hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions; the extent to which physical, chemical or biological processes are explicitly represented; or the level at which empirical parameterisations are involved.) Coupled atmosphere/ocean/sea-ice General Circulation Models (AOGCMs) provide a comprehensive representation of the climate system. There is an evolution towards more complex models with active chemistry and biology. Climate models are applied, as a research tool, to study and simulate the climate, but also for operational purposes, including monthly, seasonal and interannual climate predictions.

Climate projection

A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasise that climate projections depend upon the emission/concentration/radiative forcing scenario used, which is based on assumptions concerning, for example, future socio-economic and technological developments that may, or may not, be realised and are therefore subject to substantial uncertainty.

Climate scenario

A plausible, and often simplified, representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A "climate change scenario" is the difference between a climate scenario and the current climate.

Climate variability

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability).

Emission scenario

A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships. In 1992, the IPCC presented a set of emission scenarios that were used as a basis for the climate projections in the Second Assessment Report. These emission scenarios are referred to as the IS92 scenarios. In the IPCC Special Report on Emission Scenarios, emission scenarios – the so-called SRES scenarios – were published.

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[22] Definitions of terms here are taken from the glossary of the IPCC (McCarthy *et al.*, 2001)

Extreme weather event
An event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare as, or rarer than, the 10th or 90th percentile. By definition, the characteristics of what is called "extreme weather" may vary from place to place. An "extreme climate event" is an average of a number of weather events over a certain period of time – an average which is itself extreme (e.g., rainfall over a season).

(Climate) Impact assessment
The practice of identifying and evaluating the detrimental and beneficial consequences of climate change on natural and human systems.

Projection (generic)
A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasise that projections involve assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised, and are therefore subject to substantial uncertainty.

Radiative forcing
Radiative forcing is the change in the net vertical irradiance [expressed in Watts per square meter (Wm-2)] at the tropopause due to an internal change or a change in the external forcing of the climate system, such as a change in the concentration of CO_2 or the output of the Sun. Usually radiative forcing is computed after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with all tropospheric properties held fixed at their unperturbed values.

Scenario
A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a "narrative storyline".

Sensitivity
Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Stakeholders
Person or entity holding grants, concessions or any other type of value that would be affected by a particular action or policy.

Vulnerability
The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.

ACRONYMS AND ABBREVIATIONS

AIACC	Assessments of Impacts and Adaptation to Climate Change in Multiple Regions and Sectors
AOGCM	coupled Atmosphere-Ocean GCM
AR4	(IPCC) Fourth Assessment Report
CEEPA	Centre for Environmental Economics and Policy in Africa
CGE	Consultative Group of Experts for National Communications from Parties not included in Annex I to the UNFCCC
CDF	Conditional Distribution Function
CICS	Canadian Institute for Climate Studies
COP	Conference of the Parties to the UNFCCC
CRU	Climatic Research Unit (UK)
DDC	(IPCC) Data Distribution Centre
ESRL	(OAR's) Earth Systems Research Laboratory
CCIAV	Climate Change Impacts, Adaptation and Vulnerability
GCM	Global Climate Model/General Circulation Model
GEF	Global Environment Facility
IIASA	International Institute for Applied Systems Analysis
INC	Initial National Communication
IPCC	Intergovernmental Panel on Climate Change
NAI	non-Annex I
NAPAs	National Adaptation Programmes of Action
NC	National Communication
NCEP	National Centers for Environmental Prediction (US)
NCSP	National Communications Support Programme
NOAA	National Oceanic and Atmospheric Administration (US)
OAR	(NOAA's) Office for Oceanic and Atmospheric Research
PRECIS	Providing REgional Climates for Impact Studies
PSD	(ESRL's) Physical Sciences Division
RCM	Regional Climate Model
SNC	Second National Communication
SRES	(IPCC) Special Report on Emission Scenarios
TAR	(IPCC) Third Assessment Report
TGICA	(IPCC) Task Group for data and scenario support for Impact and Climate Analysis
TNC	Third National Communication
UEA	University of East Anglia (UK)
UKCIP	UK Climate Impacts Programme
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme
UNFCCC	United National Framework Convention on Climate Change
UNITAR	United Nations Institute for Training and Research
WB	World Bank
WMO	World Meteorology Organization

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